UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
NEW ENGLAND REGION
FIVE POST OFFICE SQUARE, SUITE 100, BOSTON, MA 02109

September 15, 2020

Bruce Thompson
de maximis, inc.
200 Day Hill Road, Suite 200
Windsor, CT 06095

Re: Approval of de maximis inc. report titled *Remedial Design Work Plan – Appendix A Site-wide Soils and Sediment Pre-Design Investigation Work Plan* (the "SSS PDIWP"), dated September 2020.

Nuclear Metals, Inc. Superfund Site

Dear Mr. Thompson:

EPA, in consultation with the Massachusetts Department of Environmental Protection, has completed its review of the SSS PDIWP, dated September 2020. The SSS PDIWP was revised in response to EPA comments dated July 2, 2020 and August 31, 2020. The SSS PDIWP is subject to the terms and conditions specified in the Consent Decree (CD) for Remedial Design / Remedial Action (RD/RA) for the Nuclear Metals, Inc. Site, which has an effective Date of December 6, 2019.

EPA has reviewed the revisions to the SSS PDIWP and finds that they are acceptable. Therefore, EPA approves the SSS PDIWP.

If there is any conflict between the Performance Standards as stated in the Work Plan and the Performance Standards as stated in the CD and statement of work (SOW), the CD and SOW shall control.

Please do not hesitate to contact me at (617) 918-1339 or at smith.christopher@epa.gov should you have any questions in this regard.

Sincerely,

Christopher Smith

Christopher Smith
Project Manager

NUCLEAR METALS, INC. SUPERFUND SITE

CONCORD, MASSACHUSETTS

Remedial Design Work Plan - Appendix A

Site-wide Soils and Sediment

Pre-Design Investigation Work Plan

Prepared for:

de maximis, inc.
200 Day Hill Road, Suite 200
Windsor, CT 06095

Prepared by:
HALEY
ALDRICH
465 Medford Street
Suite 2200
Boston, MA 02129

September 2020

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1 Introduction

On October 17, 2019, the United States Environmental Protection Agency (USEPA) lodged a Consent Decree (CD) with the United States District Court for the District of Massachusetts Eastern Division in connection with Civil Action No. 1:19-cv-12097-RGS. The CD was entered by the Court on December 6, 2019. The CD and the Statement of Work (SOW) provided as Appendix B to the CD describe the Remedial Design/Remedial Action (RD/RA) activities to be performed for the Nuclear Metals, Inc. (NMI) Superfund Site (Site) in Concord, Massachusetts. The RD/RA activities are to be undertaken by the Settling Defendants (SDs) to the CD, with funding contributions from the Settling Federal Agencies (SFAs).

To efficiently implement the remedy, the work will be divided five RA projects. RA Projects 1) – 4) below are outlined in Section 1.4 of the SOW. The need for RA Project 5) was identified during the Groundwater Non-Time-Critical Removal Action (NTCRA). The five RA projects are:

1) excavation and off-site disposal of contaminated sediments, underground drain lines and debris, and non-Holding Basin (HB) soil, or “Site-wide Soils and Sediments”;
2) In-Situ Sequestration (ISS) of depleted uranium (DU) in HB soil and of DU and natural uranium in overburden and bedrock groundwater or “ISS”;
3) containment of HB stabilized soil with a low-permeability vertical wall and horizontal sub-grade cover or “HB Containment”;
4) hydraulic containment and ex-situ treatment of volatile organic compounds (VOCs) and 1,4-dioxane in groundwater; and,
5) 1,4-dioxane and VOCs in bedrock groundwater.

1.1 Remedial Design Work Plan Overview

Section 3.1 of the SOW requires submittal of a Remedial Design Work Plan (RDWP) to summarize pertinent Site information, identify and describe the scopes and procedures for various pre-design investigations, describe the anticipated RD process, and discuss the RD-related deliverables and schedule.

The Record of Decision (ROD) summarizes the chemicals of concern (COCs) as the following:

- Natural uranium,
- Depleted uranium (DU),
- Metals (arsenic, copper, lead, mercury, thorium),
- Certain polycyclic aromatic hydrocarbons (PAHs),
- Polychlorinated biphenyls (PCBs),
- Certain volatile organic compounds (VOCs), and
- Certain semi-volatile organic compounds (SVOCs).

As required by Section 3.3(a) of the SOW, Pre-Design Investigation Work Plans (PDI WPs) have been prepared for the three remedial components (Site-wide Soils and Sediments, ISS, and HB Containment). Hydraulic containment and ex-situ treatment of VOCs and 1,4-dioxane in groundwater as required by the Groundwater NTCRA is operating and does not require further PDI work to complete. However, the extent of 1,4-dioxane and VOCs in groundwater in the area up gradient from the extraction well needs further delineation. Separate PDI WPs were prepared for each remedial component, and are attached to the RDWP as follows:

- Site-wide Soils and Sediment PDI WP (Appendix A)
- ISS PDI WP (Appendix B)
- HB Containment PDI WP (Appendix C)
- 1,4-dioxane and VOCs in Groundwater (Appendix D)

Section 3.4(a) of the SOW requires performance of Treatability Studies (TS) to support the ISS component of the remedy. Separate studies are needed to evaluate and select treatment materials/reagents, for high concentration DU within the HB, low concentration DU outside the HB, and isotopically natural uranium in bedrock, respectively. In addition to reagent selection, each media will require evaluation to determine the best means to apply the selected reagent. The overall Treatability Study Work Plan (TSWP) is attached as Appendix E.

The RDWP will also include the following “Supporting Deliverables”:

- To continue the Post-Removal Site Control (PRSC) requirements established pursuant to the Building NTCRA, a Site Maintenance and Inspection Plan (SMIP) is provided as Appendix F.
- Health and Safety Plan (HASP) – Appendix G
- Emergency Response Plan (ERP) – Appendix H
- Sampling and Analysis Plan: Field Sampling Plan (FSP) – Appendix I
- Sampling and Analysis Plan: Quality Assurance Project Plan (QAPP) – Appendix J
- Site Wide Monitoring Plan (SWMP) – Appendix K
- Community Relations Support Plan (CRSP) – Appendix L

1.2 Purpose

The RI was sufficient in its completeness to delineate the nature and extent of contamination such that risks to human health and the environment could be quantified and remedial decisions could be made. However, the RI was not intended to provide all of the information necessary to design a remediation. The purpose of the Pre-Design Investigation (PDI) is to obtain the information (i.e., address data gaps) needed to complete the remedial design by conducting additional field investigations.

1.3 Performance Standards

The ROD provided Remedial Action Objectives (RAOs), which are medium-specific goals that define the objective of remedial actions to protect human health and the environment. RAOs specify the COCs, potential exposure routes and receptors and provide a general description of what the cleanup will accomplish. The RAOs that are relevant for the Sitewide Soils and Sediment remedial design are:

(1) Prevent direct human exposure by a future resident (by dermal contact, ingestion, inhalation, or ionizing radiation) to soil or sediment with contaminants (DU, PCBs, PAHs, and other inorganics) that exceed risk-based standards.
(2) Protect ecological receptors from exposure to contaminants (PCBs, copper) in sediments indicative of adverse effects at the Cooling Water Recharge Pond.
(3) Protect ecological receptors from exposure to contaminants (PCBs, copper, mercury, and lead) in sediments indicative of adverse effects at the Sphagnum Bog while maintaining the physical and ecological integrity of the bog.

Achieving the RAOs is guided by cleanup levels for COCs which were specified in Tables L-2, L-3, and L-4 of the ROD for soil and sediment, respectively. The cleanup levels and are summarized in Tables 1 through 3 below.

Table 1 – Soil Cleanup Levels for the Protection of Human Health

CHEMICAL OF CONCERN	CLEANUP LEVEL	
	mg/kg	pCi/g
Benzo(a)anthracene	0.34	NA
Benzo(a)pyrene	0.22	NA
Benzo(b)fluoranthene	0.34	NA
Ideno(1,2,3-cd)pyrene	0.34	NA
Polychlorinated Biphenyls	1	NA
Arsenic	13.7	NA
Uranium	2.7	1.1
U-238	NA	0.9
U-235	NA	0.01
U-234	NA	0.15
Thorium	7.4	0.81
Th-232	NA	0.81
Polychlorinated Biphenyls	1	NA
Arsenic	13.7	NA
Uranium	2.7	1.1

Notes:

1. Refer to Table L-2 of ROD for cancer classification, target endpoints, and cleanup level basis.
2. NA – not applicable

Table 2 – Sediment Cleanup Levels for the Protection of Human Health

CHEMICAL OF CONCERN	CLEANUP LEVEL
	mg/kg
Polychlorinated Biphenyls	1

Notes:

1. Refer to Table L-3 of ROD for cancer classification, target endpoints, and cleanup level basis.

Table 3 – Sediment Cleanup Levels for the Protection of Ecological Receptors

HABITAT TYPE/NAME	EXPOSURE MEDIUM	CHEMICAL OF CONCERN	PROTECTIVE LEVEL (mg/kg)
Sphagnum Bog	Sediment	Polychlorinated Biphenyls	1.08
		Copper	176
		Lead	97.3
		Mercury	1.3

Notes:

1. Refer to Table L-4 of ROD for cleanup level basis and assessment endpoint.

1.4 Document Organization

Section 2 provides the objectives and scope of the PDIs, which in turn define the PDI methodology (Section 3). Within Section 3, the investigation approach, data quality objectives (DQOs), and sampling design is provided for each PDI. These sections refer to the FSP (Appendix I of the RDWP) for investigation methods, and to the QAPP (Appendix J of the RDWP) for analytical methods. Section 4 provides the PDI schedule, Section 5 defines contingent investigation activities, and Section 6 summarizes the reporting that will be completed to report on the PDI results.

2 Objective and Scope

The ROD identified the areas of the Site requiring remediation via excavation and off-site disposal of soil, sediment, and/or debris based on the risk characterization. The Site was separated into Exposure Areas "A" and "B" as well as Surface Water/Sediment Exposure Areas. Area "A" exposure areas represent locations where development of the Site (e.g., construction of buildings) would potentially be less impeded based on proximity to wetlands and surrounding land uses. Area "B" exposure areas represent locations where re-development that includes construction of buildings is less likely given the proximity to wetland areas. These Areas are represented on Figure 1. Additionally, as outlined in the Remedial Investigation/Feasibility Study (RI/FS), the Site was subdivided into Areas of Investigation (AOIs). The AOIs identify areas where former activities could have potentially resulted in contamination of environmental media. The AOIs are represented on Figure 1. Figure 2 shows the extent of the proposed soil and sediment required to be excavated. An overview of the PDIs that will be implemented for these areas is provided below and is summarized in Table 4.

PDI SSS-1 – Remedial Excavation Soil Characterization

Exposure Areas A4 (AOI 9), A5 (AOI 8), and B2 (AOIs 2 and 4) require remediation because they pose cumulative human health risks above $1x10^{-4}$ and/or a Hazard Index (HI) above 1 for residential use. The principal contributor to the risks in these areas is PCBs (i.e., in the absence of PCBs, cumulative risks at these areas would not have exceeded $1x10^{-4}$ or an HI of 1); the approximate limits of this area is shown on Figure 3. The remediation in these areas will address COCs to ensure that the RAOS in the ROD are met. The objective of PDI activities for these areas are to refine remedial excavation boundaries.

Area A6 (AOIs 7 and 11) requires remediation because it poses a cumulative risk above $1x10^{-4}$ and HI above 1 for residential use based primarily on the presence of depleted uranium, as well as PCBs; the approximate limits of this area is shown on Figure 3. The remedial excavation is planned to extend to the boundaries of the Area, and in doing so will address the COCs above remedial goals within this area. It is anticipated that COCs above remedial goals in subsurface soil within Area A6 (e.g., resulting from potential leaks in drain lines) will be defined as a component of the confirmatory sampling, to be conducted during the remedial implementation. A PDI to support remedial design at Area A6 is therefore not considered necessary, however additional surface soil sampling is planned at AOI 7 between the boundary of Area A6 and Area A2 to help refine the remedial design adjacent to the former waste handling area. The approximate limits of this area are shown on Figure 3.

Supplemental sampling will also be conducted around two PCB-contaminated sediment and soil samples with over 50 ppm PCB, located in AOI 4 (Cooling Water Recharge Pond) and AOI 15 (Former Transformer Pad Soil Area). The goal of this sampling is to identify the limits of soil and sediment with 50 ppm or greater such that that soil will be excavated separate from other materials on-site and managed at a TSCA-approved disposal facility as outlined in Appendix G of the ROD. The understood approximate limits of soil and sediment with 50 ppm or greater of PCBs is shown on Figure 3.

Additional sampling is also planned at Area B1/A2 (AOI 3 Landfill) to identify the limits of soil and sediment with COCs above remedial goals at the toe of the landfill adjacent to the Sphagnum Bog (shown on Figure 3). A PDI to support remedial design Area B1/A2 is not considered necessary, however additional soil and sediment sampling is planned as feasible based on subsurface conditions at the landfill between the boundary of Landfill and the Sphagnum Bog to help refine the remedial design. Once removal of buried debris has occurred as a component of the remedial implementation, additional confirmatory soil samples will be collected to determine if additional soil removal is required. Details of the methods of sampling is included in an Implementation Plan for the Depleted Uranium Penetrator Investigations included in Attachment 6.

PDI SSS-2 – Depleted Uranium Penetrator Investigation

Investigations were completed during the NTCRA to characterize areas of the Site where DU metal fragments (e.g., penetrators and penetrator fragments) may exist in surface soil. The characterization efforts, which are described in the "Depleted Uranium Metal Exterior Site Characterization Survey Report ([NTCRA Survey]"; September 2014), identified discrete fragments of DU metal in soil near the edge of parking areas, building exteriors, and the fence line, as well as elevated radiation measurements on some paved surfaces. Metal fragments identified during the characterization activities, as well as the adjacent soil, were removed during the NTRCA. However, these findings resulted in incorporating the paved surfaces surrounding the buildings and the adjacent wood line/fence line areas into the Site-wide soil remediation, under the assumption that soil, paved surfaces, and potentially soil beneath paved surfaces, could contain DU fragments.

Areas of the Site that contain DU fragments require remediation to remove the metal fragments. In addition, DU metal oxidation in the environment can result in soil contamination with DU, as evidenced by yellow/green discoloration of soil surrounding penetrators during the NTCRA Survey. The objective of the PDI activities for the DU penetrators are to identify DU fragments in shallow soil and characterize uranium concentrations in soil where fragments are identified. Soil beneath paved areas will be evaluated for the presence of penetrators when the pavement is removed as a component of the remedial implementation. Details of the methods of the survey are included in the DU Penetrator Investigation Implementation Plan in Attachment 6 .

PDI SSS-3 – Subslab Soil Characterization

Soil beneath the building floor slabs was not investigated during the RI/FS. However, a subslab soil investigation was performed during the building NTRCA. The results of the subslab soil investigation indicated that contamination in soil beneath the floor slabs is primarily limited to uranium. No VOCs or PCBs were detected above screening levels and PAH detections above remedial goals were limited to a single sample that was co-located with elevated uranium concentrations above the remedial goal. Thorium was also detected in several samples at concentrations above the remedial goal. However, the thorium concentrations were within the range of concentrations reported during the RI, which were determined to be consistent with background, and the pattern of thorium concentrations in subslab soil had no apparent association with uranium or other constituents.

The subslab soil sampling did not establish the lateral and vertical extent of uranium above the remedial goal. However, nearly half of the samples exhibited uranium at concentrations below the remedial goal, and only 7 out of 26 samples exhibited uranium at significantly elevated concentrations (e.g., more than ten-times the remedial goal). Complete delineation of soil beneath the floor slabs can only be performed once the building floor slabs are removed, as a component of sampling during the remedial implementation. However, a PDI will be performed for soil beneath the floor slabs in areas identified as having utilities and the potential for impacts at depth. The objective of the PDI is to further evaluate potential releases from floor drains, sumps, and subslab piping, as well as the vertical extent of uranium above the remedial goal.

PDI SSS-4 –Cooling Pond, Sphagnum Bog, and Landfill Excavation Evaluations

Remediation of the Cooling Pond sediment is based on ecological risks associated with copper and PCBs, and human health risks associated with PCBs . The extent of the sediment remediation is defined by the physical boundaries of the pond (as existed during the RI). However, excavation of pond sediments may compromise the stability of the Gabion Wall on the north end of the pond and the surrounding side slopes. The area north of the Cooling Pond will be surveyed using Ground Penetrating Radar (GPR). Restoration of the pond will need to consider its function and value as a wetland as well as the potential for contaminated groundwater to migrate into the pond and potentially re-contaminate clean substrate used to reconstruct the pond.

The objectives of the PDI for the Cooling Pond include:

- Evaluating stability of the Gabion Wall and surrounding slopes;
- Evaluating the potential for buried debris on the upland side of the Gabion Wall using a geophysical survey;
- Evaluating groundwater-surface water interaction; and
- Identifying the function and values of the Cooling Pond as a wetland resource.

Remediation of the Sphagnum Bog sediment is based on ecological risks associated with several COCs, including PCBs, uranium, and copper. The remedial boundary was determined by the area of the lag zone in the southwestern portion of the bog that contained the highest concentrations of the ecological COCs. The purpose of the PDI for the bog is to identify the sediment that can be removed, and the methods appropriate for removing it, without causing irreparable harm to the bog. The PDI for the bog will also evaluate the toe of the Landfill along the edge of the bog with respect to slope stability and methods of excavation.

Area B1/A2 (AOI 3 Landfill) was identified for remediation based on a commitment to remove the buried debris defined in the RI. The risk assessment demonstrated that risks associated with this area did not exceed EPA risk management thresholds; therefore, no COCs were identified as remedial drivers for this area. However, the presence of buried debris precluded full soil investigation within the Landfill during the RI and will preclude additional intrusive investigation of soil as a component of the PDI. The remediation of the landfill will address the buried debris within the Landfill . As a component of the buried debris removal, confirmatory soil samples will be collected and soil will be remediated to ensure that the RAOs in the ROD are met. To provide information on the location of buried debris in the landfill, a geophysical survey of the landfill will be performed as a PDI. The GPR survey will assist in delineating the depth necessary to excavate and to identify if there are known metallic objects.

PDI SSS-5 – Borrow Source Evaluation and Regrading Evaluations

The proposed remedial soil excavations result in the need for fill to be brought onsite to backfill the excavations to establish subgrade elevations for redevelopment. It may not be necessary to backfill to existing grades, but there will be a need for either off-site fill or on-site material to be used as backfill. The purpose of this PDI is to perform a chemical and geotechnical characterization of soil on-Site that could potentially be used as a borrow source.

Table 4 – Summary of PDI Objectives and PDI Scope for Soil and Sediment Excavation

SITE AREA	PDI OBJECTIVES	PDI INVESTIGATION	PDI SCOPE
A4 (AOI 9) soil	PCBs and other COC delineation at northeast outfall area	**PDI-SSS-1**	Collect surface and shallow subsurface soil samples to refine delineation of COCs.
A5 (AOI 8) soil	PCBs and other COC delineation at sweepings pile	**PDI-SSS-1**	Conduct borings to refine delineation of COCs.
B2 (AOI 2 & AOI 4) soil	PCBs and other COC delineation within Cooling Pond Area	**PDI-SSS-1**	Collect surface and shallow subsurface samples to refine delineation of COCs. No samples are required at A6, but samples will be collected between A2/A4 and A6
AOI 7	Uranium and other COC delineation along the edge of the former Waste Handling Area	**PDI-SSS-1**	Collect surface and shallow subsurface soil samples to refine delineation of COCs.
AOI 15 & AOI 4	PCBs above 50 ppm and other COC delineation	**PDI-SSS-1**	Collect surface and shallow subsurface soil samples to refine delineation of COCs.
B1/A2 (AOI 3)	COC delineation within the Old Landfill Soil Area	**PDI-SSS-1**	Collect surface and shallow subsurface soil samples to refine delineation of COCs.
DU penetrators	Mapping of DU metal fragments and areal extent of removal actions	**PDI-SSS-2**	Collect surface and shallow subsurface samples at locations of DU penetrators identified during NTCRA to confirm removal of penetrators; perform field radiation scanning of shallow soil in fence line survey units established during NTCRA.
Building footprints	Delineate uranium (based on subslab soil investigation performed as part of NTCRA)	**PDI-SSS-3**	Conduct borings through the existing floor slab to further evaluate the presence of COCs, to refine delineation of COCs for future excavation, and to evaluate impacts from utilities.
Cooling Pond, Landfill and Bog area	Bog sediment removal, landfill limits and Define subsurface conditions above Gabion Wall	**PDI-SSS-4**	Define wetland boundary, habitat types and species inventory to develop a restoration plan for the bog. EM and GPR Survey of Landfill and area above Gabion Wall to evaluate methods of landfill excavation, including support along the toe of slope of landfill and bog interface, and potential limits of excavation above Gabion Wall to reduce lateral loads on the wall.

SITE AREA	PDI OBJECTIVES	PDI INVESTIGATION	PDI SCOPE
Cooling Pond Functions and GW-SW Interactions	Cooling Pond sediment removal methods and Gabion Wall stability analysis	**PDI-SSS-4**	Define surface water and groundwater interactions within the Cooling Pond by installing piezometers along toe of slope and within the Cooling Pond footprint. Collect data on sediment, groundwater and surface water chemistry to confirm that excavation and replacement of sediment will not result in recontamination of new sediment. Means and methods of excavation for removal of Cooling Pond sediments will be evaluated based on sediment gradation, consistency, and strength as well as Gabion Wall Stability. This is also part of Slope Stability analysis discussed in Appendix C.
Borrow Source Evaluation and Regrading Evaluation	Evaluate soil type and volume, and chemical testing of soil available from on-site borrow source	**PDI-SSS-5**	Conduct borings to characterize the soil gradation, volume of potential soil that could be used as backfill on-site. Chemical testing of the soil for reuse will be conducted to meet risk-based criteria for future site use of the on-site borrow material.

3 Investigation Methodology

This section describes the investigation approach and data quality objectives (DQOs) for each of the PDIs. DQOs are qualitative and quantitative statements derived from the outputs of each step of the investigative process. The DQO process is a series of planning steps based on the scientific method that is designed to ensure that the type, quantity and quality of environmental data used in decision making applicable to the remedial design are appropriate for the intended application.

The seven (7) steps of the DQO process include:

- Stating the problem
- Identifying the decision
- Identifying inputs to the decision
- Defining the boundaries of the study
- Developing a decision rule
- Specifying limits on decision errors
- Optimizing the design for obtaining data

The sampling design and rationale for each of the PDIs is also provided within the discussion of the investigation approach and DQOs. The investigation methods are described in detail in Attachments 1 through 5.

3.1 PDI SSS-1

Investigation Design
The objective of PDI SSS-1 is to define the horizontal and vertical extent of soil excavation at AOI 9 (Area A4), AOI 8 (Area A5), AOI 2 and 4 (Area B2), AOI 3 (Area B1/A2), AOI 7, and AOI 15 that is required to meet the RAOs. The remedial boundaries at these areas will be informed by using both RI and PDI data.

The PDI for these areas has been developed by evaluating the RI data in the context of the cleanup levels. PDI sample locations that are proposed to delineate and refine the areas requiring excavation are noted on the figures in Attachment 1. These locations are intended as an initial delineation and may require additional sampling to refine the limits of excavation. Confirmatory sampling will also be required during excavation. Figures 1-1 through 1-5 and Tables 1 through 5 in Attachment 1 provide a consolidated summary of the PDI investigation locations. Although PCBs and uranium are the primary COCs at these areas, all soil samples will be analyzed for the entire list of soil COCs for completeness and to support residual risk assessment. Field investigation and analytical methods referenced in Attachment 1 are provided in the FSP and QAPP, respectively. Sampling means and methods are included in the Soil and Sediment Implementation Plan included in Attachment 6.

DQOs
Inputs to the decision will include the existing analytical data for soil samples collected during the RI and the analytical data for soil samples collected during the implementation of PDI SSS-1.

Spatial boundaries of the investigation will be the areas identified on Figures 1-1 through 1-5 in Attachment 1 and the depth of the samples below ground surface as provided in Tables 1 through 5 in Attachment 1.

Type I decision error (false rejection error):

- Conclude that excavation limits have been defined when in fact they have not
- Consequence would involve the inadequate design of the excavation (undersized excavation)

Type II decision error (false acceptance error):

- Conclude that excavation limits have not been defined when in fact they have
- Consequences involve the design of an oversized excavation

Method to optimize the design for obtaining data will include:

- Perform field and laboratory testing procedures in accordance with SOPs specified in the FSP and QAPP
- Obtain samples in accordance with SOPs and at the locations specified in Figures 1-1 through 1-4 in Attachment 1.

Type I and Type II errors will be minimized (controlled) by collecting confirmatory samples from the remedial excavation during the remedial implementation. Ultimately, the confirmatory soil sampling will be used to document that the remediation has achieved the RAOs.

3.2 PDI SSS-2

Investigation Design

The objective of PDI SSS-2 is to identify DU fragments that may exist in shallow soil in areas of the Site that are not targeted for remediation based on the results of the RI/FS, and to characterize soil in contact with the fragments to determine if it requires remediation to achieve the RAOs. The PDI therefore includes two types of investigation activities:

1) Radiation surface scanning to identify areas of elevated radioactivity followed by physical investigation of the location(s) to determine if DU fragments are present, with subsequent removal of the fragments and surrounding soil as investigation derived waste; and
2) Soil sampling at locations where elevated radioactivity is detected to evaluate soil quality and inform remedial decisions for the soil.

Although soil surrounding penetrators were removed during the NTCTRA Survey, the gamma scan instrument (sodium iodide [NaI] detector) could not provide quantitative measurements of residual uranium in soil at concentrations that met the uranium cleanup level. Therefore, the first component of the DU penetrator PDI is to perform verification soil sampling in areas where DU penetrators were removed during the NTCRA.

Following verification sampling and limited additional soil removal, if applicable, deeper soil in the Survey Units previously scanned will be investigated for the presence of DU penetrators. A PDI to evaluate the potential presence of DU penetrators in deeper soil is proposed at Survey Units (SU) 1, 2, 3, and a portion of 4 as shown in Attachment 2. The DU penetrators pose the challenge that if they are buried deeper than a few inches, they will not be detectable by typical gamma walk over surveys. The approach for detecting DU penetrators in soil deeper than six inches is to therefore remove the overlying soil to create a new soil surface, and then scan the new soil surface with a NaI detector. The PDI will be conducted by scraping back approximately 6 inches of soil within the survey units (set aside for use in back-filling after survey is complete), performing gamma scans of the newly exposed surface soil, removing DU metal and associated soil if penetrators are identified, and performing confirmatory sampling at locations where penetrators are found. If penetrators are identified, an additional 6-inch lift of soil would be removed, and the process repeated until no additional penetrators are identified.

The soil within SU 5 (within Area A6), the portion of SU 4 that abuts Area A6, and soil between Building B and Building B-4 (where DU metal was identified and removed during the NTCRA) will be remediated. A PDI for evaluating DU penetrators in deeper soil within these areas is considered unnecessary because the surface soil that may contain DU metal or residual oxidized uranium will be removed and disposed.

Within areas where surficial soil will be remediated, the underlying soil layer(s), once exposed, can be scanned and remediated for DU metal as described above. Similarly, areas beneath pavement can be scanned and remediated as necessary using the approach described above once the pavement has been removed. These activities can be implemented as a component of the remedial implementation. Additional detail on the scanning means and methods, and the management of soil is included in the DU Penetrator Investigations Implementation Plan in Attachment 6.

DQOs

Inputs to the decision will include the existing gamma scanning measurements recorded during the NTCRA, and the gamma scanning measurements and verification soil samples to be collected during implementation of PDI SSS-2.

Spatial boundaries of the investigation are described in Attachment 2. The depth of the investigation is anticipated to be 6 inches below ground surface but may extend deeper to achieve the RAOs.

Type I decision error (false rejection error):

- Conclude that DU metal fragments have been identified when in fact they have not
- Conclude that residual uranium contamination in soil meets RAOs when in fact it does not
- Consequence would involve the inadequate removal of metal fragments and/or contaminated soil

Type II decision error (false acceptance error):

- Conclude that DU metal fragments have not been identified when in fact they have
- Conclude that residual uranium contamination in soil does not meet RAOs when in fact it does
- Consequence would involve over-excavation of soil

Method to optimize the design for obtaining data will include:

- Perform field and laboratory testing procedures in accordance with SOPs specified in the FSP and QAPP
- Obtain samples in accordance with SOPs and at the locations specified in the figure contained in Attachment 2.

3.3 PDI SSS-3

Investigation Design

The objective of PDI SSS-3 is to define the horizontal and vertical extent of contaminated soil below the former building slabs related to possible leaks from former utilities. The PDI includes collecting deeper subsurface soil at the four areas where significantly elevated uranium was identified during the NTCRA subslab investigation. The results of this PDI will help to inform future slab removal and remedial excavations below the building slab.

The PDI sampling will include drilling through the concrete slab to depths of 26 feet below ground surface and collecting soil samples throughout the soil column, as described in Attachment 3. Additional detail is provided in the Soil and Sediment Sampling Implementation Plan in Attachment 6.

DQOs
Inputs to the decision will include the existing analytical data for soil samples collected during the RI and the analytical data for soil samples collected during the implementation of PDI SSS-3.

Spatial boundaries of the investigation will be the areas described in and shown on a figure as well as the depths of the samples are identified in a table contained in Attachment 3.

Type I decision error (false rejection error):

- Conclude that contamination below the slab has been defined when in fact they have not
- Consequence would involve the inadequate design of the excavation related to slab and utility removal (undersized excavation)

Type II decision error (false acceptance error):

- Conclude that the limits of contamination have not been defined when in fact they have
- Consequences involve the design of an oversized excavation related to slab and utility removal

Method to optimize the design for obtaining data will include:

- Perform field and laboratory testing procedures in accordance with SOPs specified in the FSP and QAPP
- Obtain samples in accordance with SOPs and at the locations specified on the figure contained in Attachment 3.

Type I and Type II errors will be minimized (controlled) by collecting confirmatory samples from the remedial excavation during the remedial implementation. Ultimately, the confirmatory soil sampling will be used to document that the remediation has achieved the RAOs.

3.4 PDI SSS-4

Investigation Design – Geophysical Survey
A geophysical survey will be performed within the landfill area and within the former septic system area north of the Cooling Pond (Figure 4). A geophysical survey was performed by MACTEC at the landfill in conjunction with the Remedial Investigation (RI). However, the survey was only performed within the limits of the landfill fencing and some anomalies were identified which may have been due to the metal fencing. This PDI will confirm the results documented in the RI report, and extend the survey to outside the limits of the fence. The fence will be removed, and some vegetation may need to be cleared prior to the survey.

The second geophysical survey will be performed within the former septic fields (Figure 4). This will be a due diligence survey to confirm the limits of the septic fields, and to evaluate if there are other buried debris or associated structures in the area. Subsurface components at the septic fields may include steel pipes, concrete septic tanks, concrete dosing tanks, other precast leaching structures, and other metallic waste materials that may have been buried during the construction of the septic system. The former septic field area is currently paved with a driveway and parking lot. The outcome of this PDI is to determine the limits of the septic system components that will be completely removed as part of the remedy.

Investigation Design – Slope Stability Analysis for Proposed Excavations

The bog sediment will be evaluated in terms of the strength and thickness to be used in a slope stability model. The areas of interest for slope stability include the landfill to bog slope and the steep slopes from the Holding Basin toward the bog. Sediment is to be excavated from the bog at the toe of the landfill and toe of the natural slope along the Holding Basin boundary. These excavations will require engineering controls such as sheeting to conduct the excavations without loss of ground. The future condition of backfill and potentially leaving sheeting in place will be evaluated. Details of sediment sampling methods are discussed in the Cooling Pond, Sphagnum Bog, Septic Field and Landfill Excavation Evaluation Implementation Plan in Attachment 6. Other details on the analysis is included in Appendix C, PDI HB-4.

In addition, the removal of the sediment from the bottom of the Cooling Pond will result in the potential instability of the existing Gabion Wall. Methods of excavation while maintaining the Gabion Wall integrity will be evaluated. Removal of soil from the top of the wall to reduce the lateral load on the wall will be evaluated to achieve the required excavation of the Cooling Pond soil and sediment.

Investigation Design – Groundwater and Surface Water Interactions at Cooling Pond

The remedy involves excavation of sediment within the footprint of the cooling pond. This PDI is intended to evaluate surface water and groundwater interaction to confirm that the groundwater migrating into the cooling pond will not impact the new sediment placed after excavation. The PDI will include a series of piezometers to evaluate heads and chemistry and determine if compounds present in the groundwater can partition onto the newly placed sediment. Understanding this is necessary before excavating the Cooling Pond sediment and restoring the area to pre-existing grades. Figure 5 shows the groundwater contours and proposed locations that will be investigated within the Cooling Pond to evaluate the groundwater and surface water interactions.

Investigation Design – Characterize Wetland Conditions at Bog and Cooling Pond

The interior section of the bog is primarily composed of sphagnum moss and scattered stunted or immature growth of tamarack (*Larix laricina*) growing over a layer of acidic peat. The proposed restoration area also includes a transitional scrub/shrub zone and a perimeter zone that typically has standing water and cattail growth (*Typha* sp.) and other herbaceous wetland species. Detailed field delineation and an inventory of species currently growing within these three habitat zones in the required excavation area will be a critical first step to developing a bog restoration plan, which will include soil specifications, a planting plan specific to each habitat zone, and related details.

The remediation will remove sediment to native material (likely to be a rocky substrate based on the findings from the RI). The Cooling Pond sediments (up to 3 feet deep) and the slopes to the east of the Cooling Pond require excavation. The limits of land under water will be mapped as part of this PDI.

The functions and values of the Cooling Pond as a wetland resource area will be evaluated as well as the surface water and groundwater interactions will be assessed within and around the Cooling Pond to design the restoration such that the hydrology is consistent with existing conditions.

DQOs

Inputs to the decision will include the existing analytical data for soil samples collected during the RI and the data collected during the implementation of PDI SSS-4.

Spatial boundaries of the investigation will be the areas described in and shown on Figure 5 and the depths of the samples are identified in Attachment 4.

Type I decision error (false rejection error):

- Conclude that geophysical anomalies do not exist when in fact they do
    - Consequence could involve not excavating buried debris/structures that should be removed
- Conclude that slopes are stable and/or do not require engineering solutions to stabilize them, when in fact they do
    - Consequence could be a slope failure during remedial implementation
- Conclude that groundwater will not re-contaminate Cooling Pond sediments, when in fact it may
    - Consequence would be to design a remedy that fails due to re-contamination of sediment

Type II decision error (false acceptance error):

- Conclude that geophysical anomalies exist when in fact they do not
    - Consequence could involve additional excavations that subsequently confirm there is no buried debris
- Conclude that slopes are not stable and/or do require engineering solutions to stabilize them, when in fact they do not
    - Consequence would result in engineering designs that are not necessary for remedial implementation
- Conclude that groundwater will re-contaminate Cooling Pond sediments, when in fact it will not
    - Consequence would be to design a remedy that controls groundwater recontamination of sediments, when such a remedy is not required

In addition, an incorrect characterization of wetland habitats could lead to wetland reconstruction with species that will not thrive in the wetland environments and/or compliment that functional value of the wetland.

Method to optimize the design for obtaining data will include:

- Perform field and laboratory testing procedures in accordance with SOPs specified in the FSP and QAPP
- Obtain samples in accordance with SOPs and at the locations specified on the figure contained in Attachment 4

3.5 PDI SSS-5

<u>Investigation Design – Borrow Source Investigation</u>
A borrow source evaluation will be conducted to characterize the geotechnical properties of the soil and chemical testing of the soil within the footprint of the proposed borrow source area using the investigation methods described in Attachment 5. The area of the Site near the entrance is proposed as the potential borrow source. Figure 6 shows the limits of the proposed borrow source area and the layout of explorations to characterize the soil. Observation wells will be installed in up to three of the borings for measuring groundwater elevations to define the limit of excavation of the borrow area. Excavation limits will be defined based on the groundwater elevations measured and providing adequate horizontal setbacks from abutters and the roadway.

DQOs

Inputs to the decision will include the existing analytical data for soil samples collected during the RI and the analytical data for soil samples collected during the implementation of PDI SSS-5.

Spatial boundaries of the investigation will be the areas described in and shown on Figure 6 and the depths of the samples are identified in Attachment 5.

Type I decision error (false rejection error):

- Conclude that soil is suitable as a borrow source when in fact they it is not
- Consequence would involve the use of material as a borrow source when in fact is it not suitable for such use due to either chemical contamination or geotechnical infeasibility

Type II decision error (false acceptance error):

- Conclude that soil is not suitable as a borrow source when in fact it is
- Consequences involve the conclusion that material cannot be used as a borrow source, resulting in the need to import fill material from an off-site source

Method to optimize the design for obtaining data will include:

- Perform field and laboratory testing procedures in accordance with SOPs specified in the FSP and QAPP
- Obtain samples in accordance with SOPs and at the locations specified on the figure contained in Attachment 5

4 Investigation Schedule

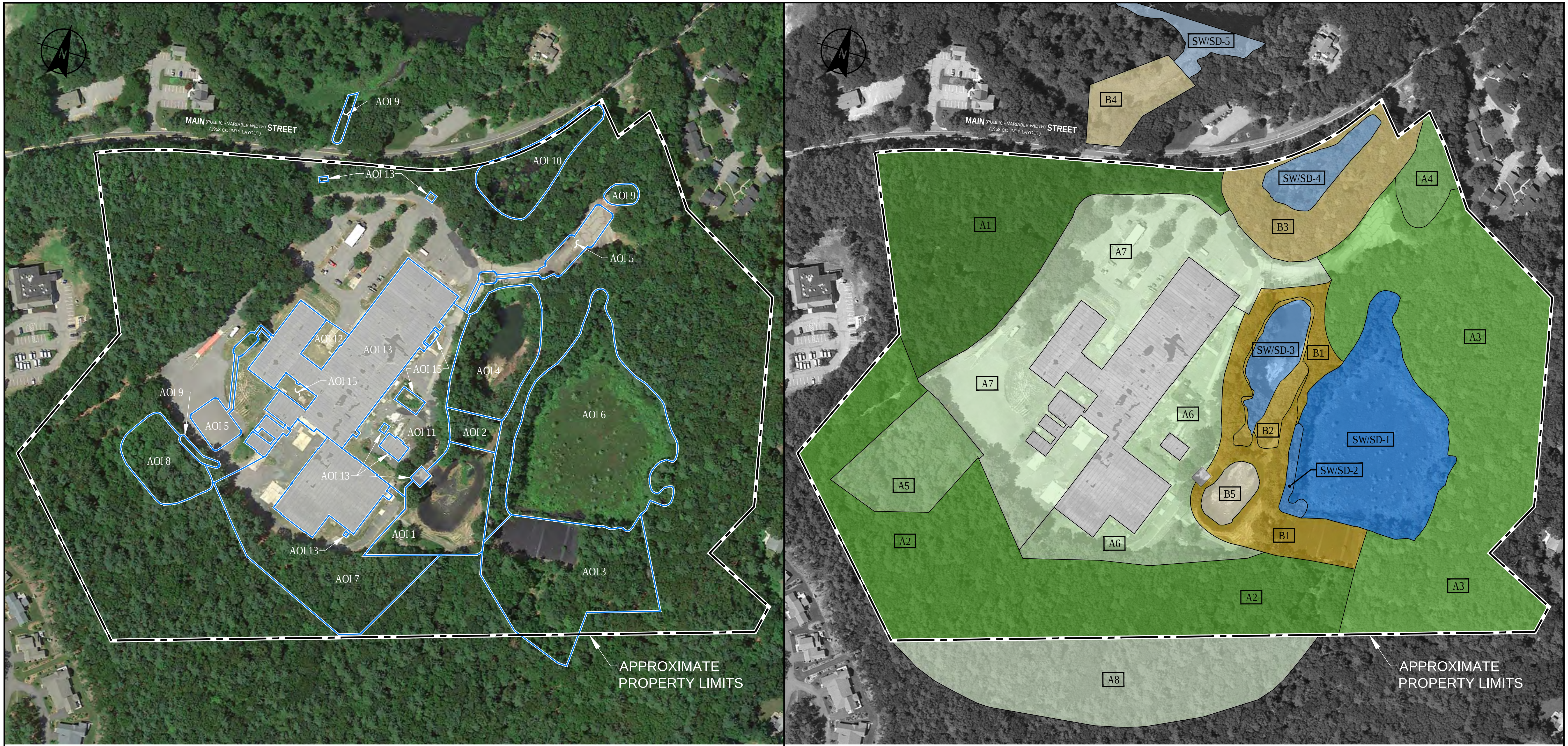
The investigation will commence after EPA’s approval of the PDI Work Plan.

5 Additional or Contingent Activities

If necessary, following review of the results, additional sampling may need to be performed to find the extent of the impacted soil and sediment.

6 Reporting

Results will be provided in a PDI Evaluation Report and the 30% RD report.



LEGEND

AOI 1 — DESIGNATION AND APPROXIMATE LOCATION OF AREA OF INVESTIGATION (AOI)

NOTES

1. BACKGROUND IMAGE, DATED 22 JUNE 2019, TAKEN ELECTRONICALLY FROM GOOGLE EARTH PRO.
2. PROPERTY LINE TAKE FROM ELECTRONIC DRAWING NAMED TITLED "17368-EC-C3D (Preliminary 2020-06-18).dwg", DATED 15 MAY 2019, BY FELDMAN LAND SURVEYORS OF BOSTON, MASSACHUSETTS.
3. LIMITS OF AREA OF INTEREST (AOI) RECEIVED ELECTRONICALLY ON 22 JULY 2022 FROM DDMS OF WALTHAM, MASSACHUSETTS.

EXPOSURE AREA		NAME
"A" EXPOSURE AREA	A1	AOI 14 WEST
	A2	AOI 14 SOUTH
	A3	AOI 14 EAST
	A4	AOI 9
	A5	AOI 8 SWEEPING AREA
	A6	AOI 7 AND 11 INDUSTRIAL AREA EAST
	A7	AOI 5 INDUSTRIAL AREA WEST
	A8	AO1 14 OFF-PROPERTY
"B" EXPOSURE AREA	B1	AREA AROUND COOLING POND
	B2	AO1 2 AND 4 SOILS AREA AT COOLING POND
	B3	AO1 10 NE WETLAND SOIL AREA
	B4	RT. 62 OUTFALL AND EMBAYMENT AREA
	B5	AO1 1 HOLDING BASIN
SURFACE WATER / SEDIMENT EXPOSURE AREAS	SW/SD-1	SPHAGNUM BOG
	SW/SD-2	SPHAGNUM BOG SW CORNER
	SW/SD-3	COOLING POND
	SW/SD-4	NE WETLAND
	SW/SD-5	ASSABET RIVER

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CONCORD, MASSACHUSETTS

EXPOSURE AREAS AND
AREAS OF INVESTIGATION

SCALE: AS SHOWN
SEPTEMBER 2020

FIGURE 1

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NOTES:

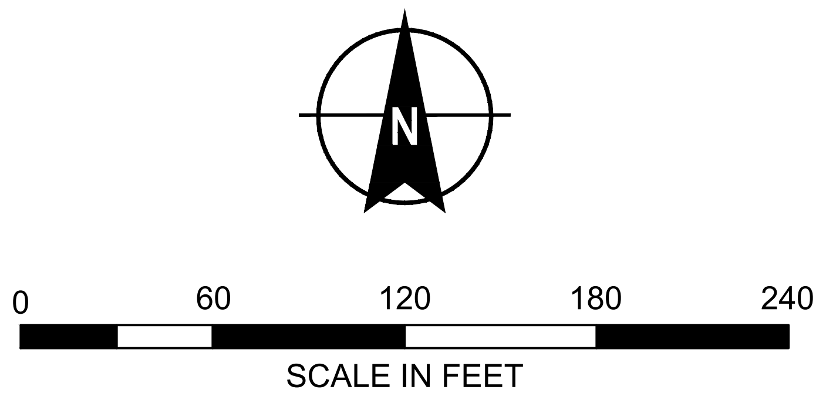
**Single PRG exceedance points (not to scale) will be excavated in an initial 2.5 foot radius, followed by confirmation sampling, and additional excavation/sampling until PRGs are met.

All underground lines within the Industrial Coutyard Area extending to the Cooling Water Recharge Pond, the Holding Pond, and the Sphaghnum Bog will be excavated in an initial 2.5 foot radius, followed by confirmation sampling, and additional excavation/sampling until PRGs are met.

All building slabs will be removed together with all soils greater than PRGs. For cost estimating, 2.5 feet of soil will be removed, except buildings C, D, and E where 5 feet will be removed.

NOTES

1. EXISTING BASEMAP REFERENCES AUTOCAD FILE "CONCORD.DWG", FROM GEOSYNTEC, DATED 2005.



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CONCORD, MASSACHUSETTS

SOIL AND SEDIMENT EXCAVATION AREAS

SCALE: AS SHOWN
SEPTEMBER 2020

FIGURE 2

DTE
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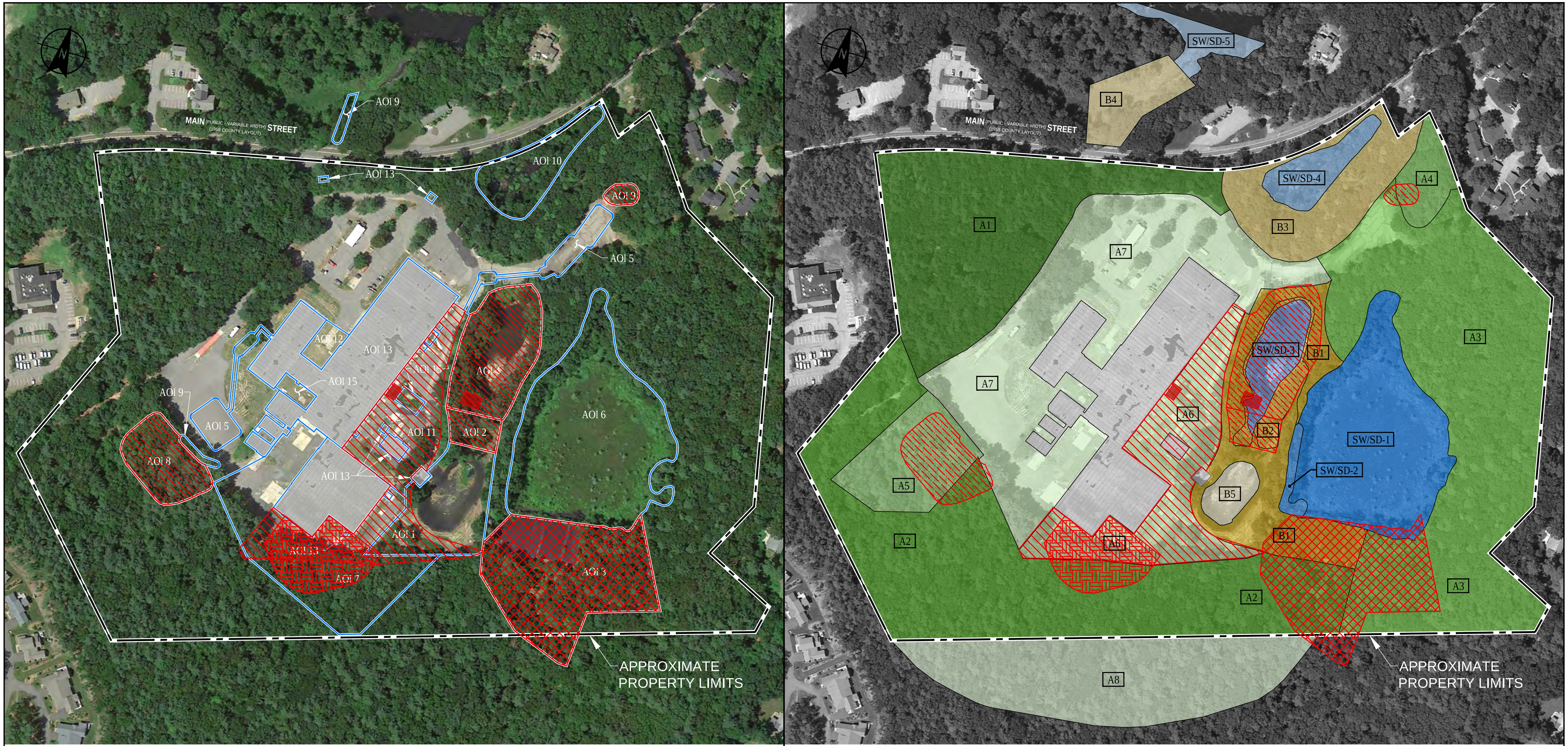

0 250 500
SCALE IN FEET

LEGEND

AOI 1 DESIGNATION AND APPROXIMATE LOCATION OF AREA OF INVESTIGATION (AOI)

NOTES

1. BACKGROUND IMAGE, DATED 22 JUNE 2019, TAKEN ELECTRONICALLY FROM GOOGLE EARTH PRO.
2. PROPERTY LINE TAKE FROM ELECTRONIC DRAWING NAMED TITLED "17368-EC-C3D (Preliminary 2020-06-18).dwg", DATED 15 MAY 2019, BY FELDMAN LAND SURVEYORS OF BOSTON, MASSACHUSETTS.
3. LIMITS OF AREA OF INTEREST (AOI) RECEIVED ELECTRONICALLY ON 22 JULY 2022 FROM DDMS OF WALTHAM, MASSACHUSETTS.

RISK LEGEND

▨ CUMULATIVE RISK > 1X10^{-4} AND / OR HAZARD INDEX > 1 FOR RESIDENTIAL USE FOR PCBS

▨ CUMULATIVE RISK > 1X10^{-4} AND / OR HAZARD INDEX > 1 FOR RESIDENTIAL USE FOR DU AND PCBS

🟥 PCBS > 50 PPM

▩ REMOVAL OF BURIED DEBRIS AND COCS IN SOIL

▦ URANIUM AND OTHER COC DELINEATION ADJACENT TO FORMER WASTE HANDLING AREA

EXPOSURE AREA		NAME
"A" EXPOSURE AREA	A1	AOI 14 WEST
	A2	AOI 14 SOUTH
	A3	AOI 14 EAST
	A4	AOI 9
	A5	AOI 8 SWEEPING AREA
	A6	AOI 7 AND 11 INDUSTRIAL AREA EAST
	A7	AOI 5 INDUSTRIAL AREA WEST
	A8	AO1 14 OFF-PROPERTY
"B" EXPOSURE AREA	B1	AREA AROUND COOLING POND
	B2	AO1 2 AND 4 SOILS AREA AT COOLING POND
	B3	AO1 10 NE WETLAND SOIL AREA
	B4	RT. 62 OUTFALL AND EMBAYMENT AREA
	B5	AO1 1 HOLDING BASIN
SURFACE WATER / SEDIMENT EXPOSURE AREAS	SW/SD-1	SPHAGNUM BOG
	SW/SD-2	SPHAGNUM BOG SW CORNER
	SW/SD-3	COOLING POND
	SW/SD-4	NE WETLAND
	SW/SD-5	ASSABET RIVER

0 250 500
SCALE IN FEET

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REMEDIAL DRIVERS FOR PDI-SSS-1

SCALE: AS SHOWN
SEPTEMBER 2020

FIGURE 3

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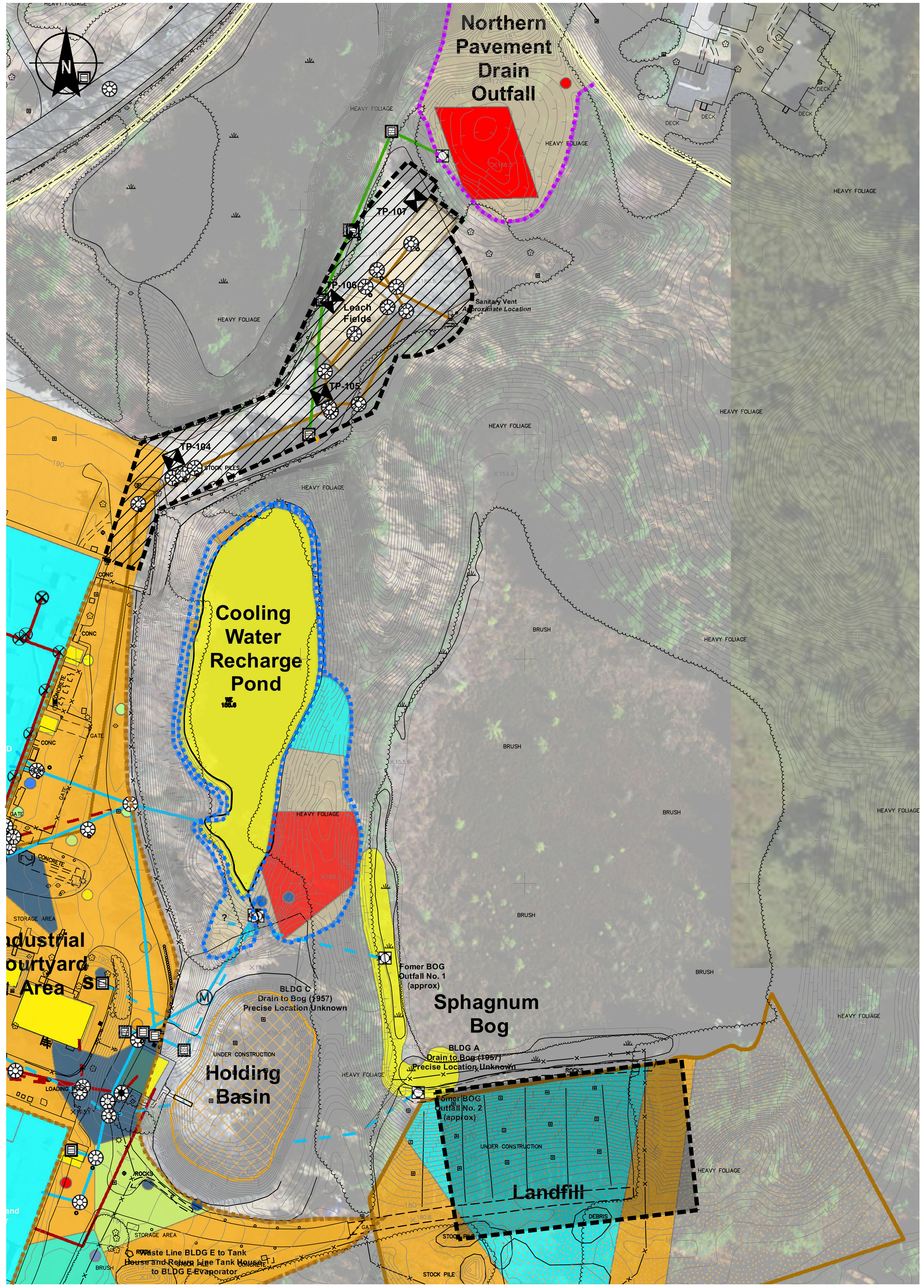

LEGEND

- ▤ Catch Basin
- Gas Gate
- S▤ Sealed Catch Basin
- Vent
- Diverter
- Ⓜ Drain Manhole
- Electric Manhole
- ⊗ Floor Drain
- Hydrant
- Manhole
- Outfall
- Valve

- Acid or Active Waste Water Drain
- Former Acid Drain
- Natural Gas
- Cooling Water
- Potable Water Supply/Fire
- Former Fire
- Sanitary
- Parking Drain
- Lines Drain to Cooling Water Pond
- Former Storm Drain
- Unknown
- Site Boundary (Approx.)
- USTs
- Septic System

Excavation Depth (ft) **

- 🟥 ● 1.00
- 🟧 ● 1.01 - 2.00
- 🟨 ● 2.01 - 3.00
- 🟩 ● 3.01 - 4.00
- 🟦 ● 4.01 - 6.00
- 🟦 ● 6.01 - 8.00
- 🟦 ● 8.01 - 10.00
- ☒ T.B.D. by remedy selection
- Remove all metal & soil to PRGs

AreaName

- Cooling Water Recharge Pond
- Industrial Courtyard Area
- Sweepings Area
- Northern Pavement Drain Outfall
- ▨ Trailer

NOTES:

**Single PRG exceedance points (not to scale) will be excavated in an initial 2.5 foot radius, followed by confirmation sampling, and additional excavation/sampling until PRGs are met.

All underground lines within the Industrial Coutyard Area extending to the Cooling Water Recharge Pond, the Holding Pond, and the Sphaghnum Bog will be excavated in an initial 2.5 foot radius, followed by confirmation sampling, and additional excavation/sampling until PRGs are met.

All building slabs will be removed together with all soils greater than PRGs. For cost estimating, 2.5 feet of soil will be removed, except buildings C, D, and E where 5 feet will be removed.

LEGEND

- ☒ PROPOSED TEST PIT ALONG FORMER SEPTIC FIELD
- ▨ APPROXIMATE LIMITS OF PROPOSED GEOPHYSICAL SURVEY

NOTES

1. EXISTING BASEMAP REFERENCES AUTOCAD FILE "CONCORD.DWG", FROM GEOSYNTEC, DATED 2005.

0 50 100 150 200

SCALE IN FEET

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PROPOSED GEOPHYSICAL SURVEY AREAS

SCALE: AS SHOWN
SEPTEMBER 2020

FIGURE 4

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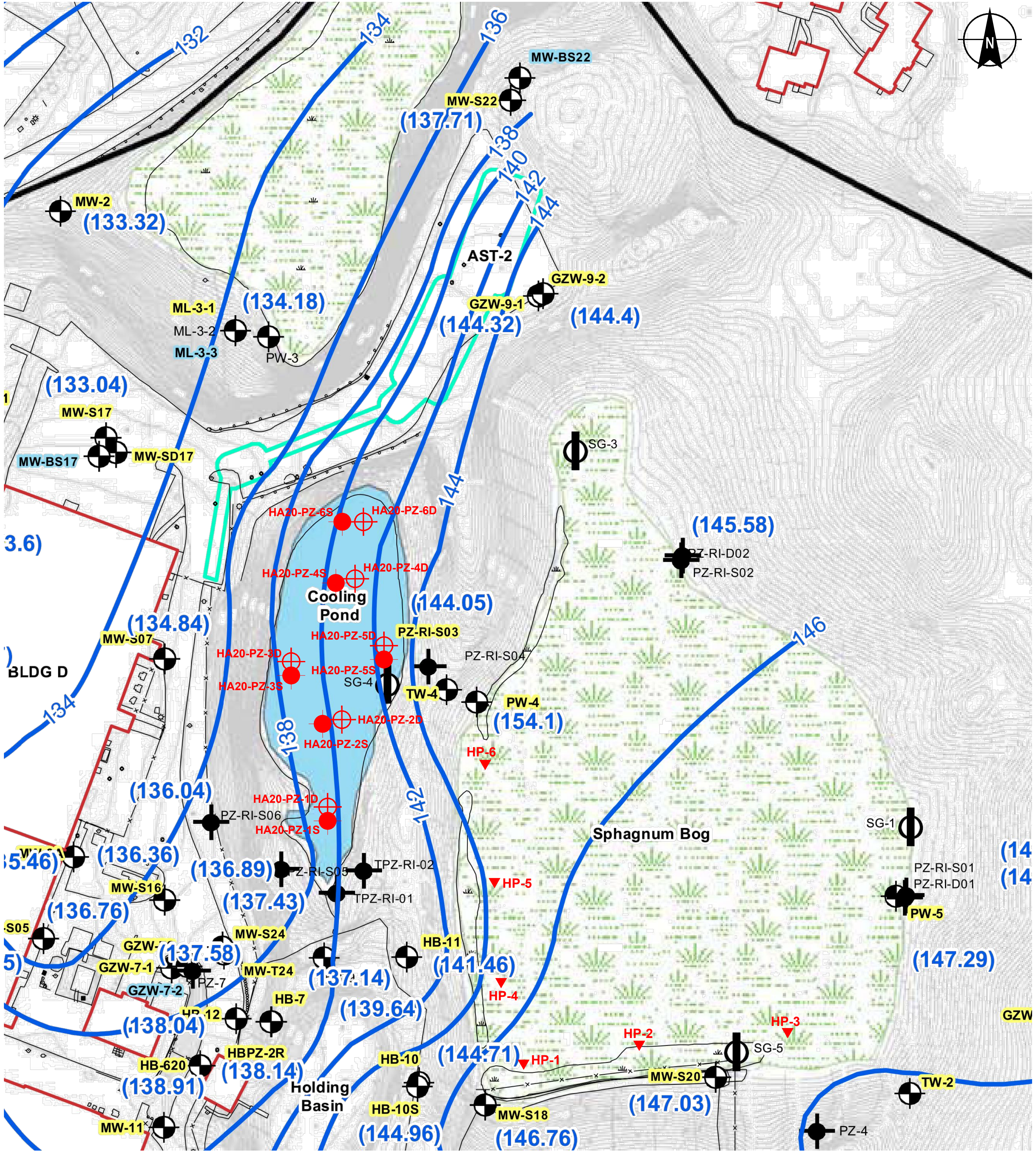

Legend

⊕	Monitoring Well
✛	Piezometer
⏀	Staff Gauge
▨	Wetlands
🟦	Surface Water
🟦	River
▭	Septic Fields
▭	Site Boundary
—	1-foot Topographic Contours
123 —	April 2008 Groundwater Elevation Contour (ft NGVD)
123 – –	April 2008 Estimated Groundwater Elevation Contour (ft NGVD)
(133.38)	Groundwater Elevation (ft NGVD)
MW-S02	Overburden Monitoring Well
MW-BS02	Bedrock Monitoring Well
MW-10	Non-functional Monitoring Well

Notes
- NGVD = National Geodetic Vertical Datum of 1929

LEGEND

HA20-PZ-1S ●	PROPOSED DRIVE-POINT PIEZOMETER (3 FT. INTO SEDIMENT)
HA20-PZ-1D ⊕	PROPOSED DRIVE-POINT PIEZOMETER (6 FT. INTO SEDIMENT)
HP-1 ▼	PROPOSED HAND PROBES TO DETERMINE THICKNESS AND STRENGTH OF PEAT

NOTE

1. BASE PLAN TAKEN FROM REMEDIAL INVESTIGATION REPORT PREPARED BY DE MAXIMIS, INC. DATED APRIL 2014.

0 100 200
SCALE IN FEET

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PROPOSED EXPLORATION PLAN - PDI SSS-4 COOLING POND AND SPHAGNUM BOG

SCALE: AS SHOWN
SEPTEMBER 2020

FIGURE 5

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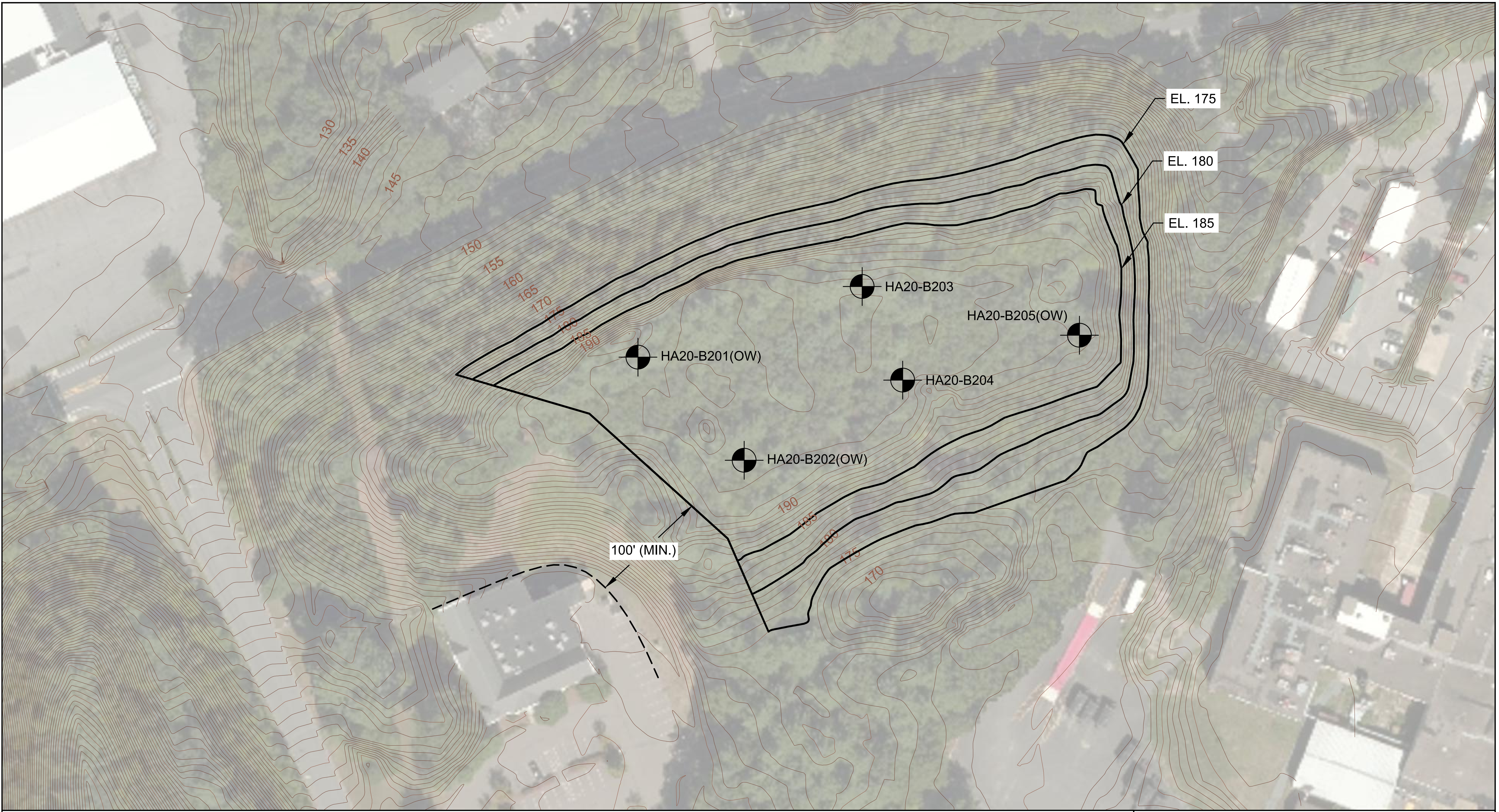

Cut/Fill Summary

Name	Cut Factor	Fill Factor	2d Area	Cut	Fill	Net
(Vol.) - EL 185	**1.000**	**1.000**	85927.74 Sq. Ft.	21238.80 Cu. Yd.	0.00 Cu. Yd.	21238.80 Cu. Yd.<Cut>
(Vol.) - EL 180	**1.000**	**1.000**	105938.81 Sq. Ft.	38982.36 Cu. Yd.	0.00 Cu. Yd.	38982.36 Cu. Yd.<Cut>
(Vol.) - EL 175	**1.000**	**1.000**	129547.39 Sq. Ft.	60677.78 Cu. Yd.	0.00 Cu. Yd.	60677.78 Cu. Yd.<Cut>

LEGEND

⊕	PROPOSED BORING LOCATION

N

0 80 160
SCALE IN FEET

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BORROW SOURCE PROPOSED EXPLORATION PLAN

SCALE: AS SHOWN
SEPTEMBER 2020

FIGURE 6

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ATTACHMENT 1 - PDI SSS-1: REMEDIAL EXCAVATION DELINEATION

1 INTRODUCTION

This Pre-Design Investigation (PDI) activity for site-wide soil and sediments (SSS) will investigate the limits of chemical of concern (COC)-impacted soil and/or sediments. The results of PDI SSS-1 will be used to design the remedy to remove soil and/or sediments impacted by COCs. The remedial excavations will be designed to achieve the Remedial Action Objectives (RAOs).

2 OBJECTIVES

The objectives for performing the testing described in this PDI are as follows:

- Collect vertical and horizontal delineation samples for site COCs in selected Areas of Interest (AOIs).
- Use the results of the PDI sampling and Remedial Investigation (RI) sampling to design remedial excavations for COCs.

The scope of work for this PDI includes collecting soil and sediment samples for site COCs as described below.

3 SCOPE OF WORK

3.1 Delineation Sampling

For the selected AOIs described herein, soil and sediment sampling will be performed to delineate horizontal and vertical limits of soil/sediment impacted by COCs. The purpose of the sampling will be to further define the limits of the remedial excavations.

At two areas of the site, AOI 4 (Cooling Water Recharge Pond) and AOI 15 (Former Transformer Pad Soil Area), polychlorinated biphenyls (PCBs) are present in soil at concentrations of 50 ppm or greater. Additional sampling is proposed to help identify the limits of this soil such that that soil will be excavated separate from other materials on-site and managed at a TSCA-approved disposal facility as outlined in Appendix G of the ROD.

The AOIs requiring additional investigation include AOI 2, AOI 4, AOI 8, and AOI 9. Additional investigations are also proposed for AOI 7, AOI 15, and AOI 3. Figure 2 of the Work Plan provides the general layout of the site features and proposed excavation areas and depths. The figures provided in Section 1 highlight the locations of the individual AOIs (Figures 1-1 through 1-7), and Figures 1-8 and 1-9 highlight the relative locations of the AOIs sitewide and the maximum concentrations of uranium and PCBs at each sampling location, respectively.

AOI 2 is referred to as the Former Drum Burial Area and is located between the Cooling Water Recharge Pond (AOI 4) and the Holding Basin (AOI 1). Based on previous investigations in this area, the impacts in AOI 2 are primarily from PCBs and are generally located in surficial soil and sediment from 0 to 1 foot, with some limited impacts at depths greater than 10 feet. The proposed sampling is intended to complete data gaps in defining the remedial excavation boundary, described in Table 1 below, and the sampling locations are shown on Figure 1-1 provided herein.

Table 1 – Proposed Sampling Plan: AOI 2 (Former Drum Burial Area)

Sampling Location	Sample Location ID Number	Medium/Matrix[1]	Depth (ft)[2]	Boring Type	Analytical Parameters[3]
SS-PD-02001	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02002	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02003	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-02004	-001-DATE	Soil	1-2	Hand Auger/ Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02005	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02006	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-02007	-001-DATE	Soil	1-2	Hand Auger/ Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02008	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-02009	-001-DATE	Soil	1-2	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
	-004-DATE	Soil	4-6		PCBs, PAHs, Uranium, Thorium, Arsenic
	-006-DATE	Soil	6-8		PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-02010	-001-DATE	Soil	1-2	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
	-004-DATE	Soil	4-6		PCBs, PAHs, Uranium, Thorium, Arsenic
	-006-DATE	Soil	6-8		PCBs, PAHs, Uranium, Thorium, Arsenic
	-008-DATE	Soil	8-10		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02011	-000-DATE	Surficial Soil	0-1	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-02011	-001-DATE	Soil	1-2		PCBs, PAHs, Uranium, Thorium, Arsenic
	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
	-004-DATE	Soil	4-6		PCBs, PAHs, Uranium, Thorium, Arsenic
	-006-DATE	Soil	6-8		PCBs, PAHs, Uranium, Thorium, Arsenic
	-008-DATE	Soil	8-10		PCBs, PAHs, Uranium, Thorium, Arsenic
	-010-DATE	Soil	10-12		PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-02012	-001-DATE	Soil	1-2	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic

Sampling Location	**Sample Location ID Number**	**Medium/Matrix[1]**	**Depth (ft)[2]**	**Boring Type**	**Analytical Parameters[3]**
	-004-DATE	Soil	4-6		PCBs, PAHs, Uranium, Thorium, Arsenic
	-006-DATE	Soil	6-8		PCBs, PAHs, Uranium, Thorium, Arsenic
	-008-DATE	Soil	8-10		PCBs, PAHs, Uranium, Thorium, Arsenic
	-010-DATE	Soil	10-12		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02013	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02014	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02015	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02016	-000-DATE	Surficial Soil	0-1	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-02016	-001-DATE	Soil	1-2		PCBs, PAHs, Uranium, Thorium, Arsenic
	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
	-004-DATE	Soil	4-6		PCBs, PAHs, Uranium, Thorium, Arsenic
	-006-DATE	Soil	6-8		PCBs, PAHs, Uranium, Thorium, Arsenic
	-008-DATE	Soil	8-10		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02017	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02018	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02019	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02020	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02021	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02022	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02023	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02024	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02025	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02026	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02027	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02028	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02029	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02030	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02031	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02032	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02033	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02034	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02035	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02036	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic

Sampling Location	Sample Location ID Number	Medium/Matrix[1]	Depth (ft)[2]	Boring Type	Analytical Parameters[3]
SS-PD-02037	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02038	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02039	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02040	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02041	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02042	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02043	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-02043	-001-DATE	Soil	1-2	Hand Auger/Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-02044	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-02044	-001-DATE	Soil	1-2	Hand Auger/Boring	PCBs, PAHs, Uranium, Thorium, Arsenic

NOTES:

1. Sample matrix is assumed to be soil. Some proposed sampling locations may be within sediments and sample collection and analysis will be adjusted accordingly to include copper, lead, and mercury.
2. Sample depths may be adjusted based on visual and/or olfactory evidence.
3. Analytical methods:
    a. Uranium, Thorium, Copper, Lead, and Arsenic by EPA Method 6020
    b. Mercury by EPA Method 7471A
    c. PCBs by EPA Method 8082 with Soxhlet Extraction
    d. PAHs by EPA Method 8270

AOI 4 is referred to as the Cooling Water Recharge Pond and surrounding soil. It is located north of the Former Drum Burial Area (AOI 2). Based on previous investigations in this area, the impacts in AOI 4 are primarily from PCBs and are located in soil and sediment ranging from 0 to 6 feet. The proposed sampling is intended to complete data gaps in defining the remedial excavation boundary and is described in Table 2 below, and the sampling locations are shown on Figure 1-2 provided herein.

Table 2 – Proposed Sampling Plan: AOI 4 (Cooling Water Recharge Pond)

Sampling Location	Sample Location ID Number	Medium/Matrix[1]	Depth (ft)[2]	Boring Type	Analytical Parameters[3]
SS-PD-04001	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04002	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04003	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04004	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04005	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic

Sampling Location	Sample Location ID Number	Medium/Matrix[1]	Depth (ft)[2]	Boring Type	Analytical Parameters[3]
SS-PD-04006	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04007	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04008	-000-DATE	Surficial Soil	0-1	Hand Auger/ Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-04008	-001-DATE	Soil	1-2		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04009	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04010	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04011	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04012	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04013	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04014	-000-DATE	Surficial Soil	0-1	Hand Auger/ Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-04014	-001-DATE	Soil	1-2		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04015	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04016	-000-DATE	Surficial Soil	0-1	Hand Auger/ Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-04016	-001-DATE	Soil	1-2		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04017	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04018	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04019	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04020	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04021	-000-DATE	Surficial Soil	0-1	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-04021	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04022	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04023	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04024	-000-DATE	Surficial Soil	0-1	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-04024	-001-DATE	Soil	1-2		PCBs, PAHs, Uranium, Thorium, Arsenic
	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04025	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04026	-000-DATE	Surficial Soil	0-1	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-04026	-001-DATE	Soil	1-2		PCBs, PAHs, Uranium, Thorium, Arsenic
	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04027	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04028	-000-DATE	Surficial Soil	0-1	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-04028	-001-DATE	Soil	1-2		PCBs, PAHs, Uranium, Thorium, Arsenic

Sampling Location	Sample Location ID Number	Medium/Matrix[1]	Depth (ft)[2]	Boring Type	Analytical Parameters[3]
	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04029	-000-DATE	Surficial Soil	0-1	Hand Auger/ Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-04029	-001-DATE	Soil	1-2		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04030	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04031	-000-DATE	Surficial Soil	0-1	Hand Auger/ Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-04031	-001-DATE	Soil	1-2		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04032	-000-DATE	Surficial Soil	0-1	Hand Auger/ Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-04032	-001-DATE	Soil	1-2		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04033	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04034	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04035	-000-DATE	Surficial Soil	0-1	Hand Auger/Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-04035	-001-DATE	Soil	1-2		PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-04036	-002-DATE	Soil	2-4	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-04037	-002-DATE	Soil	2-4	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-04038	-002-DATE	Soil	2-4	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-04039	-002-DATE	Soil	2-4	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04040	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-04040	-001-DATE	Soil	1-2	Hand Auger/Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-04041	-002-DATE	Soil	2-4	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
	-004-DATE	Soil	4-6		PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-04042	-001-DATE	Soil	1-2	Hand Auger/Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-04043	-002-DATE	Soil	2-4	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
	-004-DATE	Soil	4-6		PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-04044	-001-DATE	Soil	1-2	Hand Auger/Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-04045	-001-DATE	Soil	1-2	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-04046	-002-DATE	Soil	2-4	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-04047	-001-DATE	Soil	1-2	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-04048	-001-DATE	Soil	1-2	Hand Auger/Boring	PCBs, PAHs, Uranium, Thorium, Arsenic

Sampling Location	Sample Location ID Number	Medium/Matrix[1]	Depth (ft)[2]	Boring Type	Analytical Parameters[3]
SB-PD-04049	-001-DATE	Soil	1-2	Hand Auger/Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04050	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-04050	-001-DATE	Soil	1-2	Hand Auger/Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04051	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-04051	-001-DATE	Soil	1-2	Hand Auger/Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-04052	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-04052	-001-DATE	Soil	1-2	Hand Auger/Boring	PCBs, PAHs, Uranium, Thorium, Arsenic

NOTES:

1. Sample matrix is assumed to be soil. Some proposed sampling locations may be within sediments and sample collection and analysis will be adjusted accordingly to include copper, lead, and mercury.
2. Sample depths may be adjusted based on visual and/or olfactory evidence.
3. Analytical methods:
    a. Uranium, Thorium, Copper, Lead, and Arsenic by EPA Method 6020
    b. Mercury by EPA Method 7471A
    c. PCBs by EPA Method 8082 with Soxhlet Extraction
    d. PAHs by EPA Method 8270

AOI 8 is referred to as the Sweepings and Fill Soil Area, which is located in the southwest corner of the site. Based on previous investigations in this area, the impacts in AOI 8 are primarily from PCBs and are located in soil ranging from 0 to 4 feet. The proposed sampling is intended to complete data gaps in defining the remedial excavation boundary and is described in Table 3 below, and the sampling locations are shown on Figure 1-3 provided herein.

Table 3 – Proposed Sampling Plan: AOI 8 (Sweepings and Fill Soil Area)

Sampling Location	Sample Location ID Number	Medium/Matrix	Depth (ft)[1]	Exploration Type	Analytical Parameters[2]
SS-PD-08001	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08002	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08003	-001-DATE	Soil	1-2	Hand Auger/Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08004	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08005	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08006	-002-DATE	Soil	2-4	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic

Sampling Location	Sample Location ID Number	Medium/Matrix	Depth (ft)[1]	Exploration Type	Analytical Parameters[2]
SB-PD-08007	-002-DATE	Soil	2-4	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08008	-004-DATE	Soil	4-6	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08009	-002-DATE	Soil	2-4	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08010	-002-DATE	Soil	2-4	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08011	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08012	-000-DATE	Surficial Soil	0-1	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08012	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08013	-000-DATE	Surficial Soil	0-1	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08013	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08014	-000-DATE	Surficial Soil	0-1	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08014	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08015	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08016	-000-DATE	Surficial Soil	0-1	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08016	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08017	-002-DATE	Soil	2-4	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08018	-004-DATE	Soil	4-6	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08019	-002-DATE	Soil	2-4	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08020	-000-DATE	Surficial Soil	0-1	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08020	-001-DATE	Soil	1-2		PCBs, PAHs, Uranium, Thorium, Arsenic
	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08021	-000-DATE	Surficial Soil	0-1	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08021	-001-DATE	Soil	1-2		PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08022	-004-DATE	Soil	4-6	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08023	-000-DATE	Surficial Soil	0-1	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08023	-001-DATE	Soil	1-2		PCBs, PAHs, Uranium, Thorium, Arsenic
	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08024	-000-DATE	Surficial Soil	0-1	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08024	-001-DATE	Soil	1-2		PCBs, PAHs, Uranium, Thorium, Arsenic
	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08025	-000-DATE	Surficial Soil	0-1	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08025	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08026	-000-DATE	Surficial Soil	0-1	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic

Sampling Location	Sample Location ID Number	Medium/Matrix	Depth (ft)[1]	Exploration Type	Analytical Parameters[2]
SB-PD-08026	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08027	-004-DATE	Soil	4-6	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08028	-000-DATE	Surficial Soil	0-1	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08028	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08029	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08030	-000-DATE	Surficial Soil	0-1	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08030	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08031	-000-DATE	Surficial Soil	0-1	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08031	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08032	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08033	-000-DATE	Surficial Soil	0-1	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08033	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08034	-004-DATE	Soil	4-6	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08035	-000-DATE	Surficial Soil	0-1	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08035	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08036	-000-DATE	Surficial Soil	0-1	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08036	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08037	-000-DATE	Surficial Soil	0-1	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08037	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08038	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08039	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08040	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08041	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08042	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08043	-000-DATE	Surficial Soil	0-1	Hand Auger/Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08043	-001-DATE	Soil	1-2		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08044	-000-DATE	Surficial Soil	0-1	Hand Auger/Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08044	-001-DATE	Soil	1-2		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08045	-000-DATE	Surficial Soil	0-1	Hand Auger/Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08045	-001-DATE	Soil	1-2		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08046	-000-DATE	Surficial Soil	0-1	Hand Auger/Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08046	-001-DATE	Soil	1-2		PCBs, PAHs, Uranium, Thorium, Arsenic

Sampling Location	Sample Location ID Number	Medium/Matrix	Depth (ft)[1]	Exploration Type	Analytical Parameters[2]
SS-PD-08047	-000-DATE	Surficial Soil	0-1	Hand Auger/Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08047	-001-DATE	Soil	1-2		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08048	-000-DATE	Surficial Soil	0-1	Hand Auger/Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08048	-001-DATE	Soil	1-2		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-08049	-000-DATE	Surficial Soil	0-1	Hand Auger/Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-08049	-001-DATE	Soil	1-2		PCBs, PAHs, Uranium, Thorium, Arsenic

NOTES:

1. Sample depths may be adjusted based on visual and/or olfactory evidence.
2. Analytical methods:
   a. Uranium, Thorium, and Arsenic by EPA Method 6020
   b. PCBs by EPA Method 8082 with Soxhlet Extraction
   c. PAHs by EPA Method 8270

AOI 9 is referred to as the Northern Pavement Drain Outfall Area, which is located in the northeast corner of the site. Based on previous investigations in this area, the impacts in AOI 9 are primarily from PCBs and are generally located in surficial soil from 0 to 1 foot. The proposed sampling is intended to complete data gaps in defining the remedial excavation boundary and is described in Table 4 below, and the sampling locations are shown on the attached Figure 1-4 provided herein.

Table 4 – Proposed Sampling Plan: AOI 9 (Northern Pavement Drain Outfall Area)

Sampling Location	Sample Location ID Number	Medium/ Matrix	Depth (ft)[1]	Exploration Type	Analytical Parameters[2]
SS-PD-09001	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-09002	-001-DATE	Soil	1-2	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-09003	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-09004	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-09005	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-09006	-001-DATE	Soil	1-2	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-09007	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-09008	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-09009	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-09010	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic

NOTES:

1. Sample depths may be adjusted based on visual and/or olfactory evidence.
2. Analytical methods:

  a. Uranium, Thorium, and Arsenic by EPA Method 6020
  b. PCBs by EPA Method 8082 with Soxhlet Extraction
  c. PAHs by EPA Method 8270

AOI 7 is referred to as the Former Waste Handling Area. It is located beneath the slab of former Building E (the southernmost building addition) and includes soil to the south of Building E. Remedial excavations are already planned to the extend to the boundaries of this area, however additional surficial delineation is proposed to refine the limits of excavation. The proposed sampling plan is described in Table 5 below, and the sampling locations are shown on the attached Figure 1-5 provided herein.

Table 5 – Proposed Sampling Plan: AOI 7 (Former Waste Handling Area)

Sampling Location	Sample Location ID Number	Medium/ Matrix	Depth (ft)[1]	Exploration Type	Analytical Parameters[2]
SS-PD-07001	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-07001	-001-DATE	Soil	1-2	Hand Auger/Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-07002	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-07002	-001-DATE	Soil	1-2	Hand Auger/Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-07003	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-07003	-001-DATE	Soil	1-2	Hand Auger/Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-07004	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-07004	-001-DATE	Soil	1-2	Hand Auger/Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-07005	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-07005	-001-DATE	Soil	1-2	Hand Auger/Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-07006	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-07006	-001-DATE	Soil	1-2	Hand Auger/Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-07007	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-07007	-001-DATE	Soil	1-2	Hand Auger/Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-07008	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-07008	-001-DATE	Soil	1-2	Hand Auger/Boring	PCBs, PAHs, Uranium, Thorium, Arsenic

NOTES:

1. Sample depths may be adjusted based on visual and/or olfactory evidence.
2. Analytical methods:
   a. Uranium, Thorium, and Arsenic by EPA Method 6020

   b. PCBs by EPA Method 8082 with Soxhlet Extraction
   c. PAHs by EPA Method 8270

AOI 15 is referred to as the Transformer Pads Soil Area. Remedial excavations are already planned in this area, however additional delineation is proposed to refine the limits of soil with concentrations of PCBs greater than 50 ppm. The proposed sampling plan is described in Table 6 below, and the sampling locations are shown on the attached Figure 1-6 provided herein.

Table 6 – Proposed Sampling Plan: AOI 15 (Transformer Pad Soil Area)

Sampling Location	**Sample Location ID Number**	**Medium/Matrix**	**Depth (ft)[1]**	**Exploration Type**	**Analytical Parameters[2]**
SB-PD-15001	-002-DATE	Soil	2-4	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-15002	-002-DATE	Soil	2-4	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-15003	-004-DATE	Soil	4-6	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-15004	-000-DATE	Surficial Soil	0-1	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-15004	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
	-004-DATE	Soil	4-6		PCBs, PAHs, Uranium, Thorium, Arsenic
	-006-DATE	Soil	6-8		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-15005	-000-DATE	Surficial Soil	0-1	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-15005	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-15006	-001-DATE	Soil	1-2	Hand Auger/ Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-15007	-000-DATE	Surficial Soil	0-1	Hand Auger	PCBs, PAHs, Uranium, Thorium, Arsenic

NOTES:

1. Sample depths may be adjusted based on visual and/or olfactory evidence.
2. Analytical methods:
   a. Uranium, Thorium, and Arsenic by EPA Method 6020
   b. PCBs by EPA Method 8082 with Soxhlet Extraction
   c. PAHs by EPA Method 8270

AOI 3 is referred to as the Old Landfill Soil Area. Remedial excavations are already planned in this area, however additional delineation is proposed to refine the limits of impacted soil adjacent to the Sphagnum Bog. The proposed sampling plan is described in Table 7 below, and the sampling locations are shown on the attached Figure 1-7 provided herein. Sampling in this area may be adjusted based on the presence of subsurface obstructions within the limits of the landfill.

Table 7 – Proposed Sampling Plan: AOI 3 (Old Landfill Soil Area)

Sampling Location	Sample Location ID Number	Medium/Matrix	Depth (ft)[1]	Exploration Type	Analytical Parameters[2]
SS-PD-03001	-000-DATE	Surficial Soil	0-2	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-03001	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
	-004-DATE	Soil	4-6		PCBs, PAHs, Uranium, Thorium, Arsenic
	-006-DATE	Soil	6-8		PCBs, PAHs, Uranium, Thorium, Arsenic
	-008-DATE	Soil	8-10		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-03002	-000-DATE	Surficial Soil	0-2	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-03002	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
	-004-DATE	Soil	4-6		PCBs, PAHs, Uranium, Thorium, Arsenic
	-006-DATE	Soil	6-8		PCBs, PAHs, Uranium, Thorium, Arsenic
	-008-DATE	Soil	8-10		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-03003	-000-DATE	Surficial Soil	0-2	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-03003	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
	-004-DATE	Soil	4-6		PCBs, PAHs, Uranium, Thorium, Arsenic
	-006-DATE	Soil	6-8		PCBs, PAHs, Uranium, Thorium, Arsenic
	-008-DATE	Soil	8-10		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-03004	-000-DATE	Surficial Soil	0-2	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-03004	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
	-004-DATE	Soil	4-6		PCBs, PAHs, Uranium, Thorium, Arsenic
	-006-DATE	Soil	6-8		PCBs, PAHs, Uranium, Thorium, Arsenic
	-008-DATE	Soil	8-10		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-03005	-000-DATE	Surficial Soil	0-2	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-03005	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
	-004-DATE	Soil	4-6		PCBs, PAHs, Uranium, Thorium, Arsenic
	-006-DATE	Soil	6-8		PCBs, PAHs, Uranium, Thorium, Arsenic
	-008-DATE	Soil	8-10		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-03006	-000-DATE	Surficial Soil	0-2	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-03006	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
	-004-DATE	Soil	4-6		PCBs, PAHs, Uranium, Thorium, Arsenic
	-006-DATE	Soil	6-8		PCBs, PAHs, Uranium, Thorium, Arsenic
	-008-DATE	Soil	8-10		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-03007	-000-DATE	Surficial Soil	0-2	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-03007	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
	-004-DATE	Soil	4-6		PCBs, PAHs, Uranium, Thorium, Arsenic

Sampling Location	Sample Location ID Number	Medium/Matrix	Depth (ft)[1]	Exploration Type	Analytical Parameters[2]
	-006-DATE	Soil	6-8		PCBs, PAHs, Uranium, Thorium, Arsenic
	-008-DATE	Soil	8-10		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-03008	-000-DATE	Surficial Soil	0-2	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-03008	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
	-004-DATE	Soil	4-6		PCBs, PAHs, Uranium, Thorium, Arsenic
	-006-DATE	Soil	6-8		PCBs, PAHs, Uranium, Thorium, Arsenic
	-008-DATE	Soil	8-10		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-03009	-000-DATE	Surficial Soil	0-2	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-03009	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
	-004-DATE	Soil	4-6		PCBs, PAHs, Uranium, Thorium, Arsenic
	-006-DATE	Soil	6-8		PCBs, PAHs, Uranium, Thorium, Arsenic
	-008-DATE	Soil	8-10		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-03010	-000-DATE	Surficial Soil	0-2	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-03010	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
	-004-DATE	Soil	4-6		PCBs, PAHs, Uranium, Thorium, Arsenic
	-006-DATE	Soil	6-8		PCBs, PAHs, Uranium, Thorium, Arsenic
	-008-DATE	Soil	8-10		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-03011	-000-DATE	Surficial Soil	0-2	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-03011	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
	-004-DATE	Soil	4-6		PCBs, PAHs, Uranium, Thorium, Arsenic
	-006-DATE	Soil	6-8		PCBs, PAHs, Uranium, Thorium, Arsenic
	-008-DATE	Soil	8-10		PCBs, PAHs, Uranium, Thorium, Arsenic
SS-PD-03012	-000-DATE	Surficial Soil	0-2	Boring	PCBs, PAHs, Uranium, Thorium, Arsenic
SB-PD-03012	-002-DATE	Soil	2-4		PCBs, PAHs, Uranium, Thorium, Arsenic
	-004-DATE	Soil	4-6		PCBs, PAHs, Uranium, Thorium, Arsenic
	-006-DATE	Soil	6-8		PCBs, PAHs, Uranium, Thorium, Arsenic
	-008-DATE	Soil	8-10		PCBs, PAHs, Uranium, Thorium, Arsenic

NOTES:

4. Sample matrix is assumed to be soil. Some proposed sampling locations may be within sediments and sample collection and analysis will be adjusted accordingly to include copper, lead, and mercury.
5. Sample depths may be adjusted based on visual and/or olfactory evidence.
6. Analytical methods:
   - a. Uranium, Thorium, Copper, Lead, and Arsenic by EPA Method 6020
   - b. Mercury by EPA Method 7471A
   - c. PCBs by EPA Method 8082 with Soxhlet Extraction
   - d. PAHs by EPA Method 8270

4 PROCEDURES

The procedures described below are augmented by the field sampling and laboratory procedures described in the Field Sampling Plan (FSP) and Quality Assurance Project Plan (QAAP). Additional detail of the sampling methods are included in the Soil and Sediment Sampling Implementation Plan in Attachment 6.

4.1 Surficial Soil Sampling

For surficial soil (0 to 1 foot), sampling is proposed to be completed using a hand auger. Direct push (Geoprobe) and/or hollow-stem auger drill rig may be necessary for surficial soil sampling depending on field conditions (e.g., frozen soil, cobbles, etc.).

Samples will be collected by compositing the entire 1-foot depth in a stainless-steel bowl or aluminum pan. The volume of collected material will be stirred to homogenize the sample and then placed in appropriate glassware for submission to the laboratory.

Samples are planned to be submitted for laboratory analysis of PCBs, polycyclic aromatic hydrocarbons (PAHs) (benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, and indeno(1,2,3-cd)pyrene), uranium, thorium, and arsenic. The proposed analytical methods are provided below:

- PCBs by EPA Method 8082 with Soxhlet Extraction
- PAHs by EPA Method 8270
- Uranium, Thorium, and Arsenic by EPA Method 6020

4.2 Subsurface Soil Sampling

For deeper soil (greater than 1-foot depth), sampling is generally proposed to be completed by direct push (Geoprobe) and/or hollow-stem auger drill rig. Depending on field conditions, shallow subsurface samples (up to 2 feet) may be completed using a hand auger.

Samples will be collected by compositing select depths (generally on a 1 to 2 feet basis) in a stainless-steel bowl or aluminum pan. The volume of collected material will be stirred to homogenize the sample and then placed in appropriate glassware for submission to the laboratory.

Samples are planned to be submitted for laboratory analysis of PCBs, PAHs (benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, and indeno(1,2,3-cd)pyrene), uranium, thorium, and arsenic. The proposed analytical methods are provided below:

- PCBs by EPA Method 8082 with Soxhlet Extraction
- PAHs by EPA Method 8270

- Uranium, Thorium, and Arsenic by EPA Method 6020

4.3 Sediment Sampling

In the Former Drum Burial Area (AOI 2) and the Cooling Water Recharge Pond (AOI 4), sediment sampling is planned to be completed using a hand auger.

Samples will be collected by compositing select depths (generally on a 1 to 2 feet basis) in a stainless-steel bowl or aluminum pan. The volume of collected material will be stirred to homogenize the sample and then placed in appropriate glassware for submission to the laboratory.

Samples are planned to be submitted for laboratory analysis of PCBs, PAHs (benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, and indeno(1,2,3-cd)pyrene), uranium, thorium, arsenic, copper, lead, and mercury. The proposed analytical methods are provided below:

- PCBs by EPA Method 8082 with Soxhlet Extraction
- PAHs by EPA Method 8270
- Uranium, Thorium, Arsenic, Copper, and Lead by EPA Method 6020
- Mercury by EPA Method 7471A

4.4 Supplemental Delineation

If necessary, following review of the results from the sampling program described above, additional sampling may need to be performed to refine the extent of the impacted soil and sediment. Delineation sampling locations will be located in proximity (e.g., approximately 10 feet away from previous sampling locations). The delineation sampling locations will be oriented on Magnetic North/South/East/West.

4.5 IDW Management

Investigation-derived waste (IDW) generated during the delineation sampling will include soil and sediment cuttings from subsurface explorations. Excess soil will be placed back within the exploration borehole to the extent possible.

5 REPORTING

The status of this PDI and potential results will be provided to EPA during routine project meetings and status reports. Results and the outcome of the PDI will be provided in the PDI Evaluation Report and incorporated into the 30% RD report.

ATTACHMENTS
SECTION 1

Figure 1-1	AOI 2 Drum Burial Pit Proposed Sample Locations
Figure 1-2	AOI 4 Cooling Water Recharge Pond Proposed Sample Locations
Figure 1-3	AOI 8 Sweepings and Fill Area Proposed Sample Locations
Figure 1-4	AOI 9 Pavement Drain Outfalls (North) Proposed Sample Locations
Figure 1-5	AOI 7 Former Waste Handling Area Proposed Sample Locations
Figure 1-6	AOI 15 Transformer Pad Proposed Sample Locations
Figure 1-7	AOI 3 Toe of Landfill Proposed Sample Locations
Figure 1-8	Sitewide Total Uranium Maximum Concentration
Figure 1-9	Sitewide Total PCBs Maximum Concentration

Figure 1-1

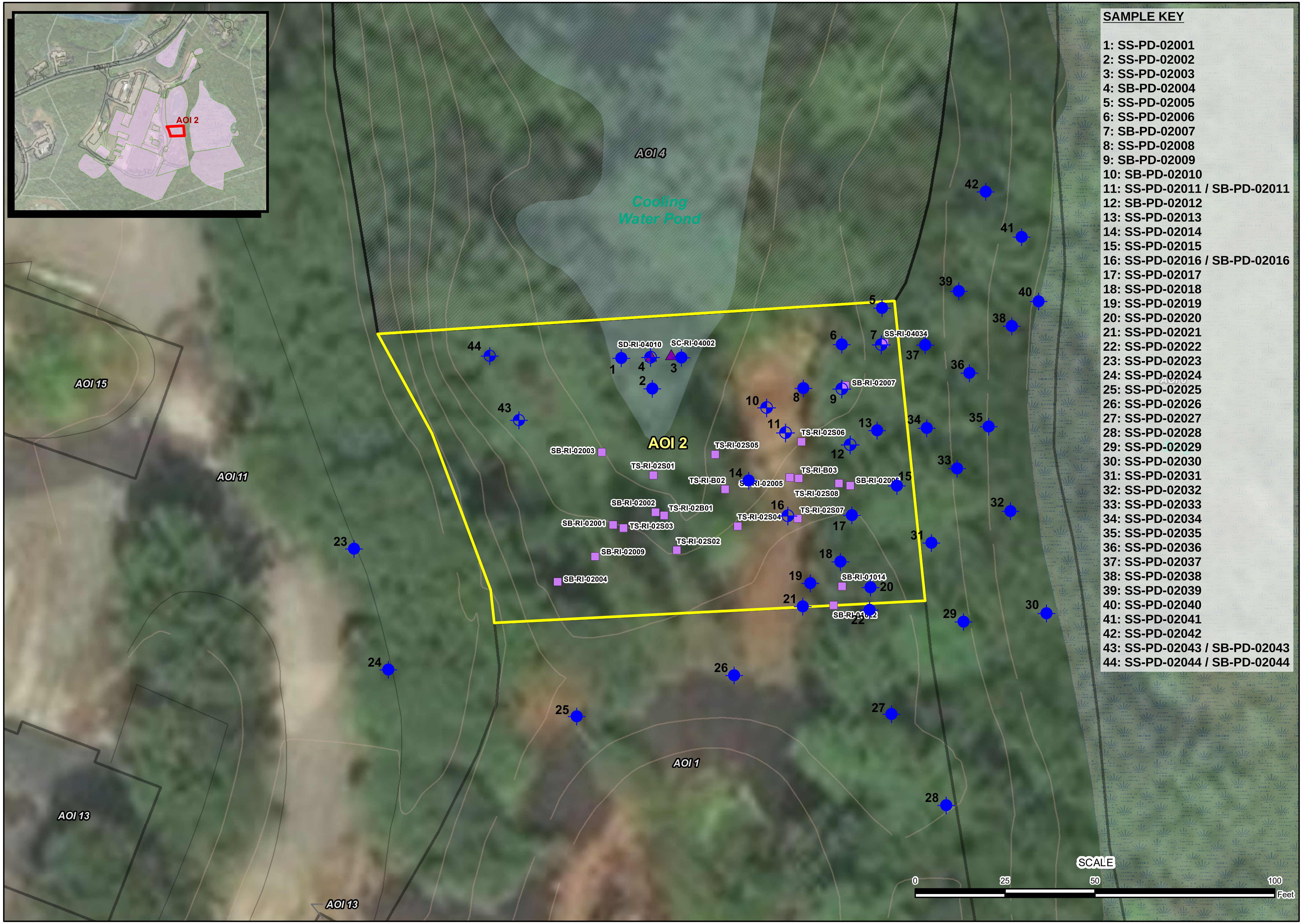
PCBs Pre-Remedial
Design Investigation

**AOI 2 Drum Burial Pit
Proposed Sample
Locations**

Nuclear Metals, Inc.
Concord, Massachusetts

Description:

Source:



SAMPLE KEY

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2: SS-PD-02002
3: SS-PD-02003
4: SB-PD-02004
5: SS-PD-02005
6: SS-PD-02006
7: SB-PD-02007
8: SS-PD-02008
9: SB-PD-02009
10: SB-PD-02010
11: SS-PD-02011 / SB-PD-02011
12: SB-PD-02012
13: SS-PD-02013
14: SS-PD-02014
15: SS-PD-02015
16: SS-PD-02016 / SB-PD-02016
17: SS-PD-02017
18: SS-PD-02018
19: SS-PD-02019
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22: SS-PD-02022
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38: SS-PD-02038
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40: SS-PD-02040
41: SS-PD-02041
42: SS-PD-02042
43: SS-PD-02043 / SB-PD-02043
44: SS-PD-02044 / SB-PD-02044

Map Legend:

▭	Area of Investigation Boundary
■	Soil Samples
▲	Sediment Samples
1 ⌖	Designation and approximate location of surficial soil sample
2 ⌖	Designation and approximate location of soil sample

Spatial Projection:

N

Coordinate System:
MA State Plane Mainland
FIPS Zone: 2001
Units: US Survey Feet
Datum: NAD83

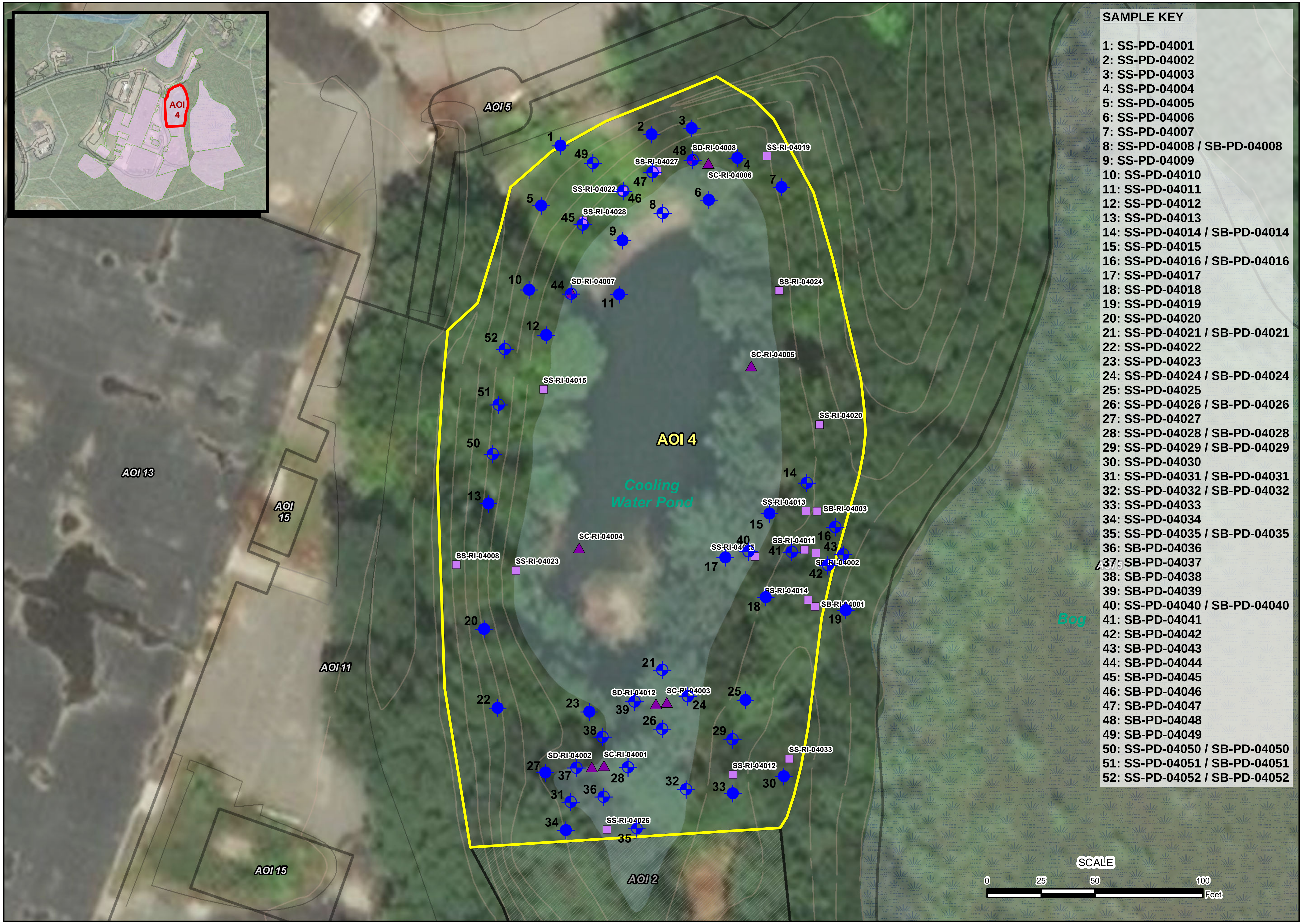
Plot Info:

Project No.: 3243
Plot Date: 3/4/2020
Arc Operator: LDS
Reviewed by: KS/EC

ddms
www.ddmsinc.com

de maximis, inc.

R:\Projects\DEF\demax-1547\3252-NMI RD & RA\DataAnalysis\GISData\Projects\PDI_Figures\PDI_Fig1-1_thru_1-4_PCBs_Proposed_Sample_Locs.mxd



SAMPLE KEY

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2: SS-PD-04002
3: SS-PD-04003
4: SS-PD-04004
5: SS-PD-04005
6: SS-PD-04006
7: SS-PD-04007
8: SS-PD-04008 / SB-PD-04008
9: SS-PD-04009
10: SS-PD-04010
11: SS-PD-04011
12: SS-PD-04012
13: SS-PD-04013
14: SS-PD-04014 / SB-PD-04014
15: SS-PD-04015
16: SS-PD-04016 / SB-PD-04016
17: SS-PD-04017
18: SS-PD-04018
19: SS-PD-04019
20: SS-PD-04020
21: SS-PD-04021 / SB-PD-04021
22: SS-PD-04022
23: SS-PD-04023
24: SS-PD-04024 / SB-PD-04024
25: SS-PD-04025
26: SS-PD-04026 / SB-PD-04026
27: SS-PD-04027
28: SS-PD-04028 / SB-PD-04028
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30: SS-PD-04030
31: SS-PD-04031 / SB-PD-04031
32: SS-PD-04032 / SB-PD-04032
33: SS-PD-04033
34: SS-PD-04034
35: SS-PD-04035 / SB-PD-04035
36: SB-PD-04036
37: SB-PD-04037
38: SB-PD-04038
39: SB-PD-04039
40: SS-PD-04040 / SB-PD-04040
41: SB-PD-04041
42: SB-PD-04042
43: SB-PD-04043
44: SB-PD-04044
45: SB-PD-04045
46: SB-PD-04046
47: SB-PD-04047
48: SB-PD-04048
49: SB-PD-04049
50: SS-PD-04050 / SB-PD-04050
51: SS-PD-04051 / SB-PD-04051
52: SS-PD-04052 / SB-PD-04052

Figure 1-2

PCBs Pre-Remedial Design Investigation

AOI 4 Cooling Water Recharge Pond Proposed Sample Locations

Nuclear Metals, Inc.
Concord, Massachusetts

Description:

Source:

Map Legend:

- ▭ Area of Investigation Boundary
- ■ Soil Samples
- ▲ Sediment Samples
- 1 ● Designation and approximate location of surficial soil sample
- 2 ⊕ Designation and approximate location of soil sample

Spatial Projection:

N

Coordinate System: MA State Plane Mainland
FIPS Zone: 2001
Units: US Survey Feet
Datum: NAD83

Plot Info:

Project No.: 3243
Plot Date: 3/4/2020
Arc Operator: LDS
Reviewed by: KS/EC

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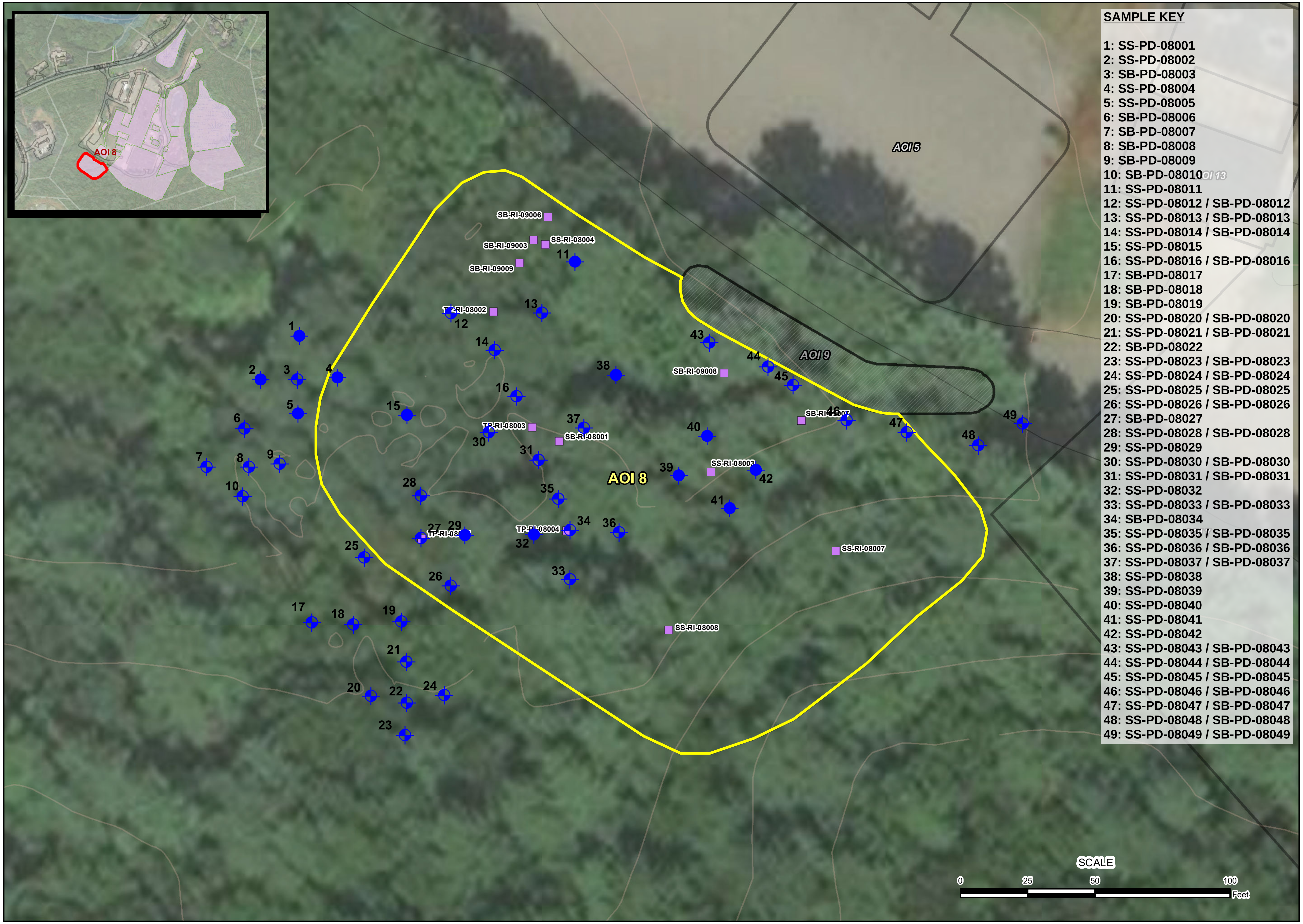
Figure 1-3

PCBs Pre-Remedial
Design Investigation

AOI 8 Sweepings and Fill Area
Proposed Sample Locations

Nuclear Metals, Inc.
Concord, Massachusetts



SAMPLE KEY

1: SS-PD-08001
2: SS-PD-08002
3: SB-PD-08003
4: SS-PD-08004
5: SS-PD-08005
6: SB-PD-08006
7: SB-PD-08007
8: SB-PD-08008
9: SB-PD-08009
10: SB-PD-08010
11: SS-PD-08011
12: SS-PD-08012 / SB-PD-08012
13: SS-PD-08013 / SB-PD-08013
14: SS-PD-08014 / SB-PD-08014
15: SS-PD-08015
16: SS-PD-08016 / SB-PD-08016
17: SB-PD-08017
18: SB-PD-08018
19: SB-PD-08019
20: SS-PD-08020 / SB-PD-08020
21: SS-PD-08021 / SB-PD-08021
22: SB-PD-08022
23: SS-PD-08023 / SB-PD-08023
24: SS-PD-08024 / SB-PD-08024
25: SS-PD-08025 / SB-PD-08025
26: SS-PD-08026 / SB-PD-08026
27: SB-PD-08027
28: SS-PD-08028 / SB-PD-08028
29: SS-PD-08029
30: SS-PD-08030 / SB-PD-08030
31: SS-PD-08031 / SB-PD-08031
32: SS-PD-08032
33: SS-PD-08033 / SB-PD-08033
34: SB-PD-08034
35: SS-PD-08035 / SB-PD-08035
36: SS-PD-08036 / SB-PD-08036
37: SS-PD-08037 / SB-PD-08037
38: SS-PD-08038
39: SS-PD-08039
40: SS-PD-08040
41: SS-PD-08041
42: SS-PD-08042
43: SS-PD-08043 / SB-PD-08043
44: SS-PD-08044 / SB-PD-08044
45: SS-PD-08045 / SB-PD-08045
46: SS-PD-08046 / SB-PD-08046
47: SS-PD-08047 / SB-PD-08047
48: SS-PD-08048 / SB-PD-08048
49: SS-PD-08049 / SB-PD-08049

Description:

Source:

Map Legend:

▭	Area of Investigation Boundary
■	Soil Samples
1 ●	Designation and approximate location of surficial soil sample
2 ⊕	Designation and approximate location of soil sample

Spatial Projection:

N

Coordinate System:
MA State Plane Mainland
FIPS Zone: 2001
Units: US Survey Feet
Datum: NAD83

Plot Info:

Project No.: 3243
Plot Date: 3/4/2020
Arc Operator: LDS
Reviewed by: KS/EC

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Figure 1-4

PCBs Pre-Remedial Design Investigation

AOI 9 Pavement Drain Outfalls (North) Proposed Sample Locations

Nuclear Metals, Inc.
Concord, Massachusetts

Description:

Source:

Map Legend:

- 🟨 Area of Investigation Boundary
- 🟪 Soil Samples
- 1 ● Designation and approximate location of surficial soil sample
- 2 ⊕ Designation and approximate location of soil sample

Spatial Projection:

N

Coordinate System:
MA State Plane Mainland
FIPS Zone: 2001
Units: US Survey Feet
Datum: NAD83

Plot Info:

File: Fig2.4.4_Pcb_>1_SS
Project No.: 3167c
Plot Date: 13 Nov., 2012
Arc Operator: HG
Reviewed by: VR/BT

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SAMPLE KEY

1: SS-PD-07001 / SB-PD-07001
2: SS-PD-07002 / SB-PD-07002
3: SS-PD-07003 / SB-PD-07003
4: SS-PD-07004 / SB-PD-07004
5: SS-PD-07005 / SB-PD-07005
6: SS-PD-07006 / SB-PD-07006
7: SS-PD-07007 / SB-PD-07007
8: SS-PD-07008 / SB-PD-07008

Figure 1-5

Pre-Remedial
Design Investigation
AOI 7 Former Waste Handling Area
Proposed Sample Locations

Nuclear Metals, Inc.
Concord, Massachusetts

Description:

Source:

Map Legend:

- ▭ Area of Investigation Boundary
- ■ Soil Samples
- 1 ⌖ Designation and approximate location of soil sample

Spatial Projection:

N
Coordinate System:
MA State Plane Mainland
FIPS Zone: 2001
Units: US Survey Feet
Datum: NAD83

Plot Info:

Project No.: 3243
Plot Date: 3/4/2020
Arc Operator: LDS
Reviewed by: KS/EC

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Figure 1-6

Pre-Remedial
Design Investigation

**AOI 15 Transformer Pad
Proposed Sample
Locations**

Nuclear Metals, Inc.
Concord, Massachusetts

Description:

Source:

Map Legend:

▭	Area of Investigation Boundary
■	Soil Samples
▲	Sediment Samples
1 ●	Designation and approximate location of surficial soil sample
2 ⊕	Designation and approximate location of soil sample

Spatial Projection:

N

Coordinate System:
MA State Plane Mainland
FIPS Zone: 2001
Units: US Survey Feet
Datum: NAD83

Plot Info:

Project No.: 3243
Plot Date: 3/4/2020
Arc Operator: LDS
Reviewed by: KS/EC

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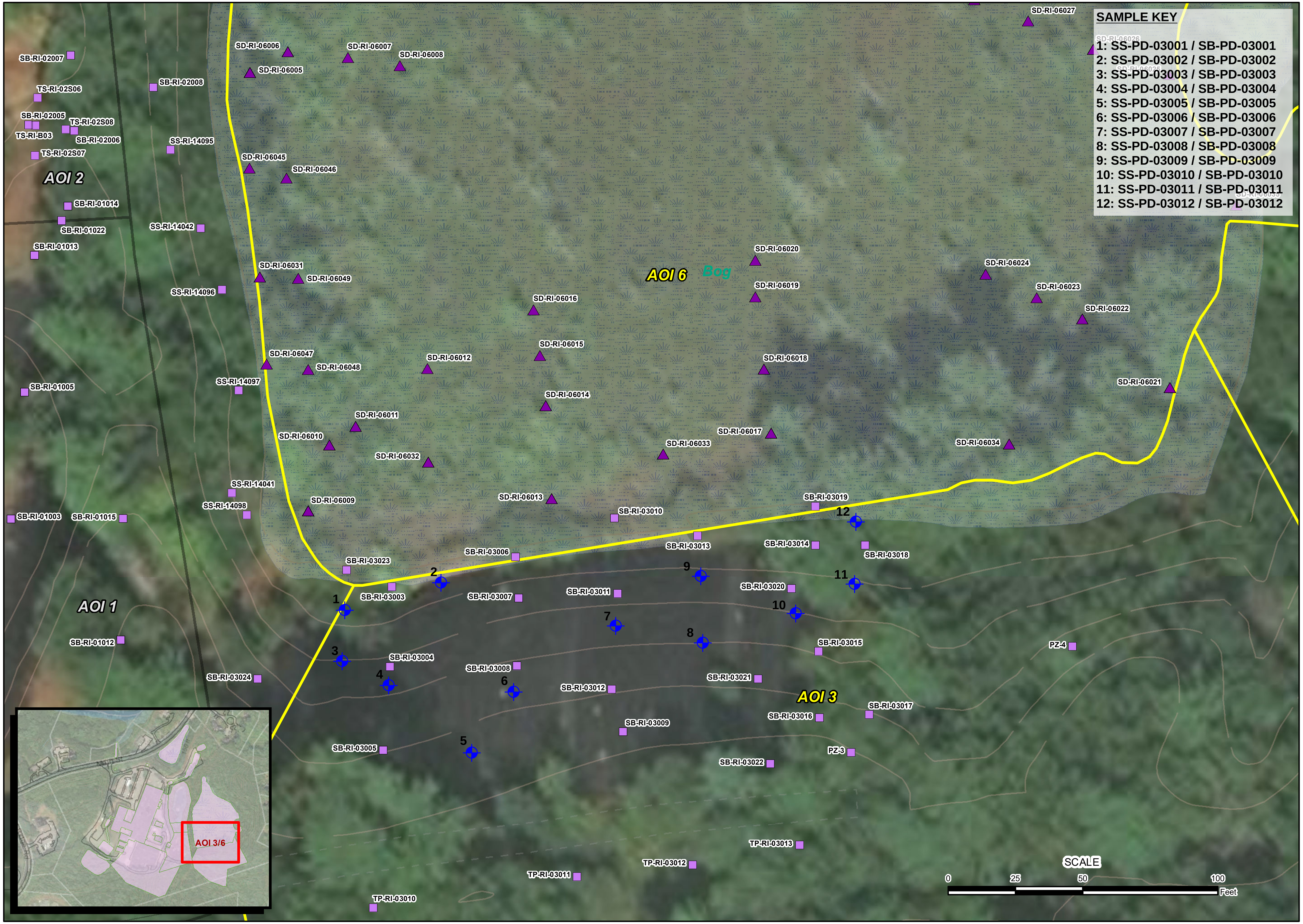

SAMPLE KEY

1: SS-PD-03001 / SB-PD-03001
2: SS-PD-03002 / SB-PD-03002
3: SS-PD-03003 / SB-PD-03003
4: SS-PD-03004 / SB-PD-03004
5: SS-PD-03005 / SB-PD-03005
6: SS-PD-03006 / SB-PD-03006
7: SS-PD-03007 / SB-PD-03007
8: SS-PD-03008 / SB-PD-03008
9: SS-PD-03009 / SB-PD-03009
10: SS-PD-03010 / SB-PD-03010
11: SS-PD-03011 / SB-PD-03011
12: SS-PD-03012 / SB-PD-03012

Figure 1-7

Pre-Remedial Design Investigation

AOI 3 Toe of Landfill Proposed Sample Locations

Nuclear Metals, Inc.
Concord, Massachusetts

Description:

Source:

Map Legend:

- 🟨 Area of Investigation Boundary
- ◻ Soil Samples
- ▲ Sediment Samples
- 1 ⊕ Designation and approximate location of surficial soil sample
- 2 ⊕ Designation and approximate location of soil sample

Spatial Projection:

N
Coordinate System:
MA State Plane Mainland
FIPS Zone: 2001
Units: US Survey Feet
Datum: NAD83

Plot Info:

Project No.: 3243
Plot Date: 3/4/2020
Arc Operator: LDS
Reviewed by: KS/EC

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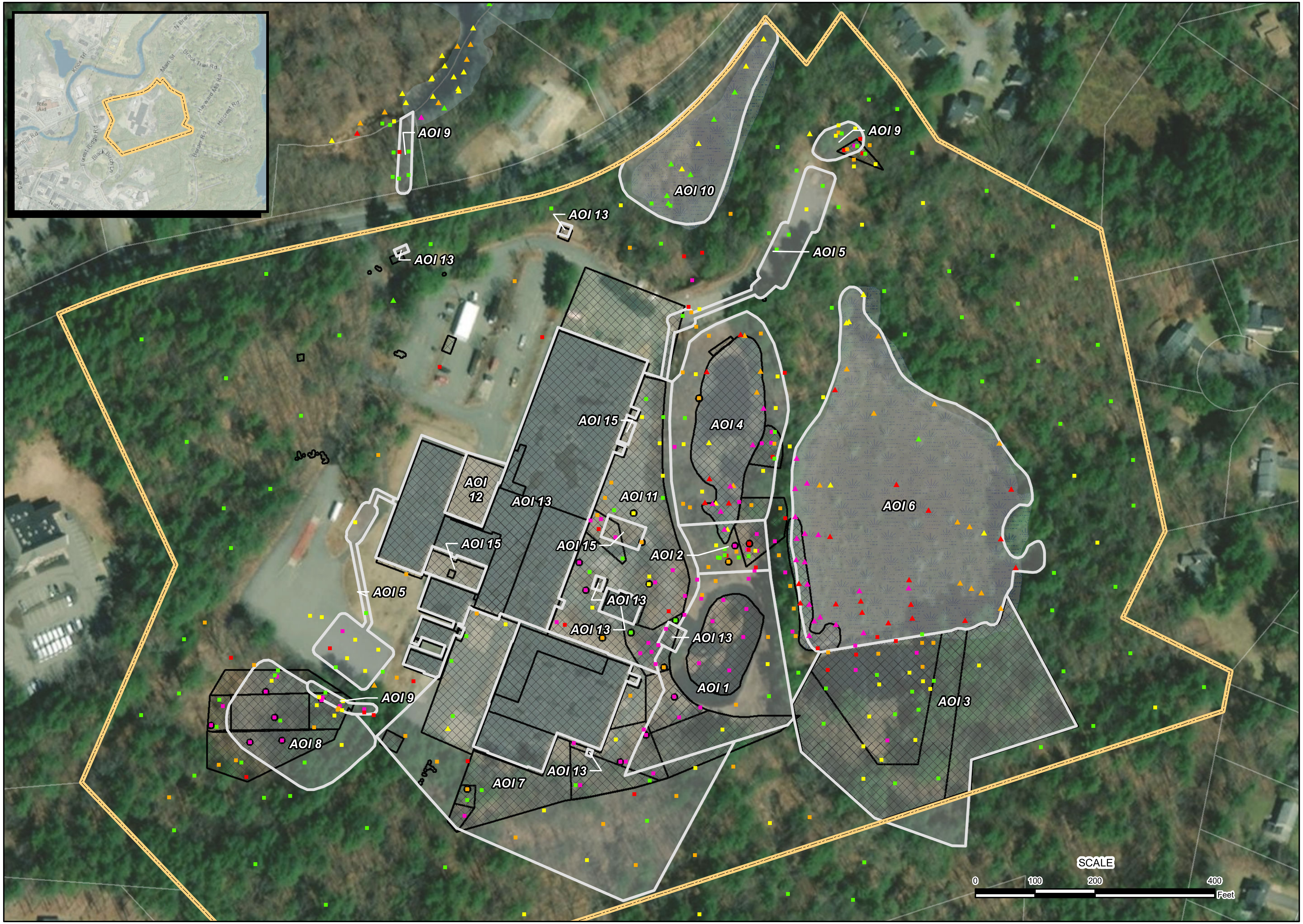

Figure 1-8

Pre-Remedial
Design Investigation

Sitewide
Total Uranium
Maximum Concentration

Nuclear Metals, Inc.
Concord, Massachusetts

URANIUM DATA POINTS RELATIVE TO ROD CLEAN-UP CRITERIA REPRESENT MAXIMUM RESULT AT THAT LOCATION

Map Legend:

- ▭ Areas of Investigation (AOI)
- ▨ ROD Excavation Boundary
- ▭ Site Boundary

Soil ROD Cleanup Criteria (2.7 mg/kg)

- ■ > 10x
- ■ > 5x
- ■ > 2x
- ■ > 1x
- ■ < Cleanup Level
- ■ ND

Sediment Cleanup Level (2.7 mg/kg)

- ▲ > 10x
- ▲ > 5x
- ▲ > 2x
- ▲ > 1x
- ▲ < Cleanup Level
- ▲ ND

Spatial Projection:

N

Coordinate System:
MA State Plane Mainland
FIPS Zone: 2001
Units: US Survey Feet
Datum: NAD83

Plot Info:

Project No.: 3243
Plot Date: 7/20/2020
Arc Operator: LDS
Reviewed by: KS/EC

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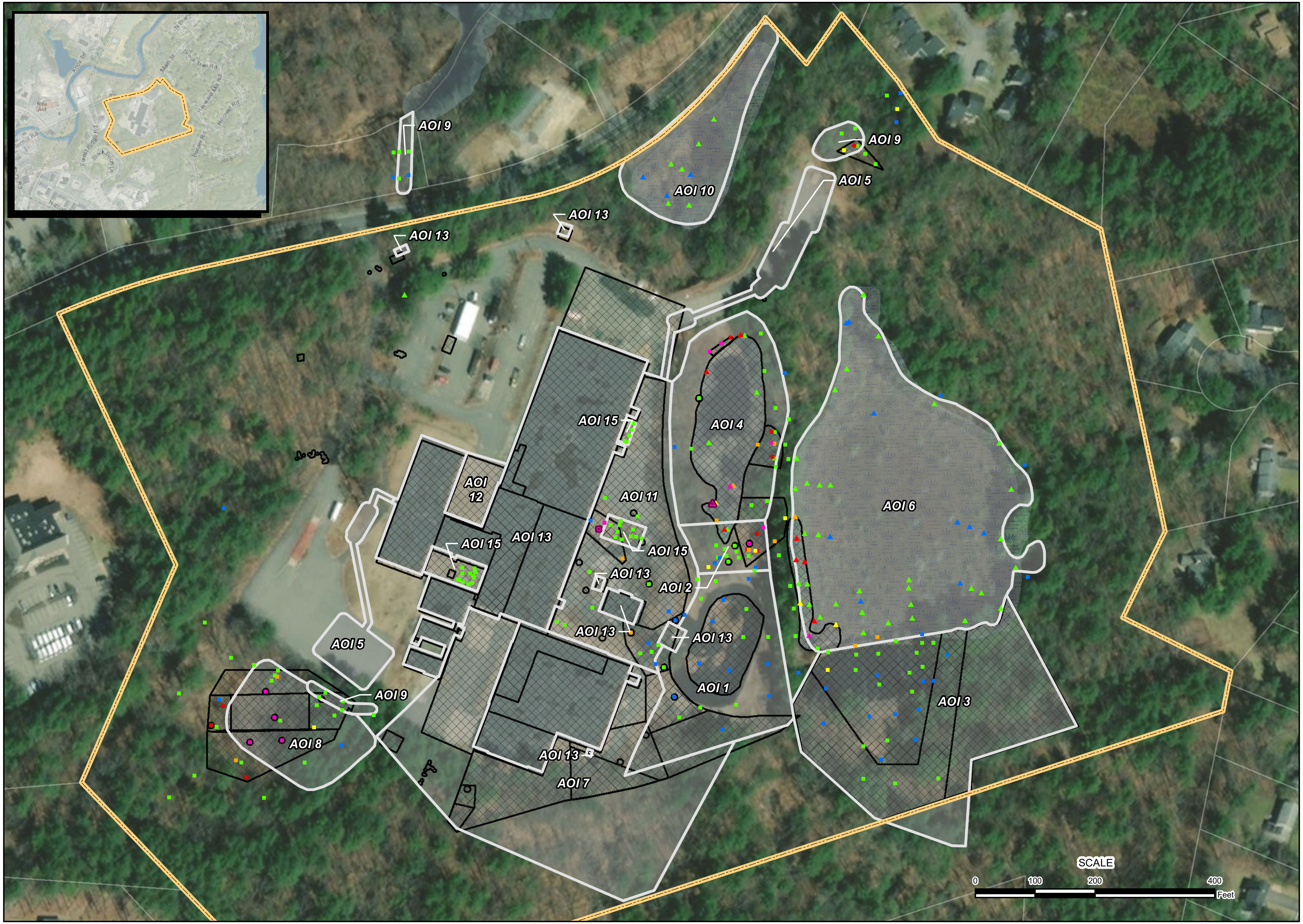

Figure 1-9

Pre-Remedial
Design Investigation

Sitewide
Total PCBs
Maximum Concentration

Nuclear Metals, Inc.
Concord, Massachusetts

PCBs DATA POINTS RELATIVE TO ROD CLEAN-UP CRITERIA REPRESENT MAXIMUM RESULT AT THAT LOCATION

Map Legend:

- ▭ Areas of Investigation (AOI)
- ▨ ROD Excavation Boundary
- ▭ Site Boundary

Soil ROD Clean Up Criteria (1.0 mg/kg)

- ■ > 50x (TCSA Cleanup Criteria)
- ■ > 10x
- ■ > 5x
- ■ > 2x
- ■ > 1x
- ■ < Cleanup Level
- ■ ND

Sediment ROD Clean Up Criteria (1.0 mg/kg)

- ▲ > 50x (TCSA Cleanup Criteria)
- ▲ > 10x
- ▲ > 5x
- ▲ > 2x
- ▲ > 1x
- ▲ < Cleanup Level
- ▲ ND

Spatial Projection:

N

Coordinate System:
MA State Plane Mainland
FIPS Zone: 2001
Units: US Survey Feet
Datum: NAD83

Plot Info:

Project No.: 3243
Plot Date: 7/20/2020
Arc Operator: LDS
Reviewed by: KS/EC

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ATTACHMENT 2 - PDI SSS-2: DEPLETED URANIUM PENETRATOR INVESTIGATION

Project	Nuclear Metal Superfund Site, Concord, MA	Date	4 September 2020
Client	Remedial Design Work Plan	Page	1 of 5

1 INTRODUCTION

This Pre-Design Investigation (PDI) activity for site-wide soils and sediments (SSS) will evaluate the presence of depleted uranium (DU) in soil from DU penetrators and metal fragments. The scope of this investigation will be based on results of the prior Non-Time-Critical Removal Actions (NTCRAs), including verifying removals performed in the NTCRAs and further evaluating areas of concern identified in the NTCRAs. The results of PDI SSS-2 will be used to confirm prior removals of soil impacted by DU penetrators/metal fragments and assess the presence of DU penetrators/metal fragments in deeper soil (greater than 6 inches deep).

2 OBJECTIVES

The objectives for this PDI are to evaluate the presence of DU penetrators and metal fragments at the site, remove any identified DU penetrators/metal fragments and associated impacted soil, and conduct confirmatory sampling at areas where DU penetrators/metal fragments were previously removed. During the NTCRAs, DU penetrators/metal fragments and visibly impacted soil were removed from several locations, however confirmatory sampling is necessary to evaluate the complete removal of impacted soil. Gamma walkover surveys are also proposed to survey deeper soil (6 inches below ground surface) in areas that are not currently proposed for remediation by excavation. DU penetrators/metal fragments and impacted soil, if found during the walkover surveys, are planned to be removed and confirmatory samples collected, as necessary. Additional details of the methods of completing the survey and how soils will be managed are included in the DU Penetrator Investigations Implementation Plan in Attachment 6.

3 SCOPE OF WORK

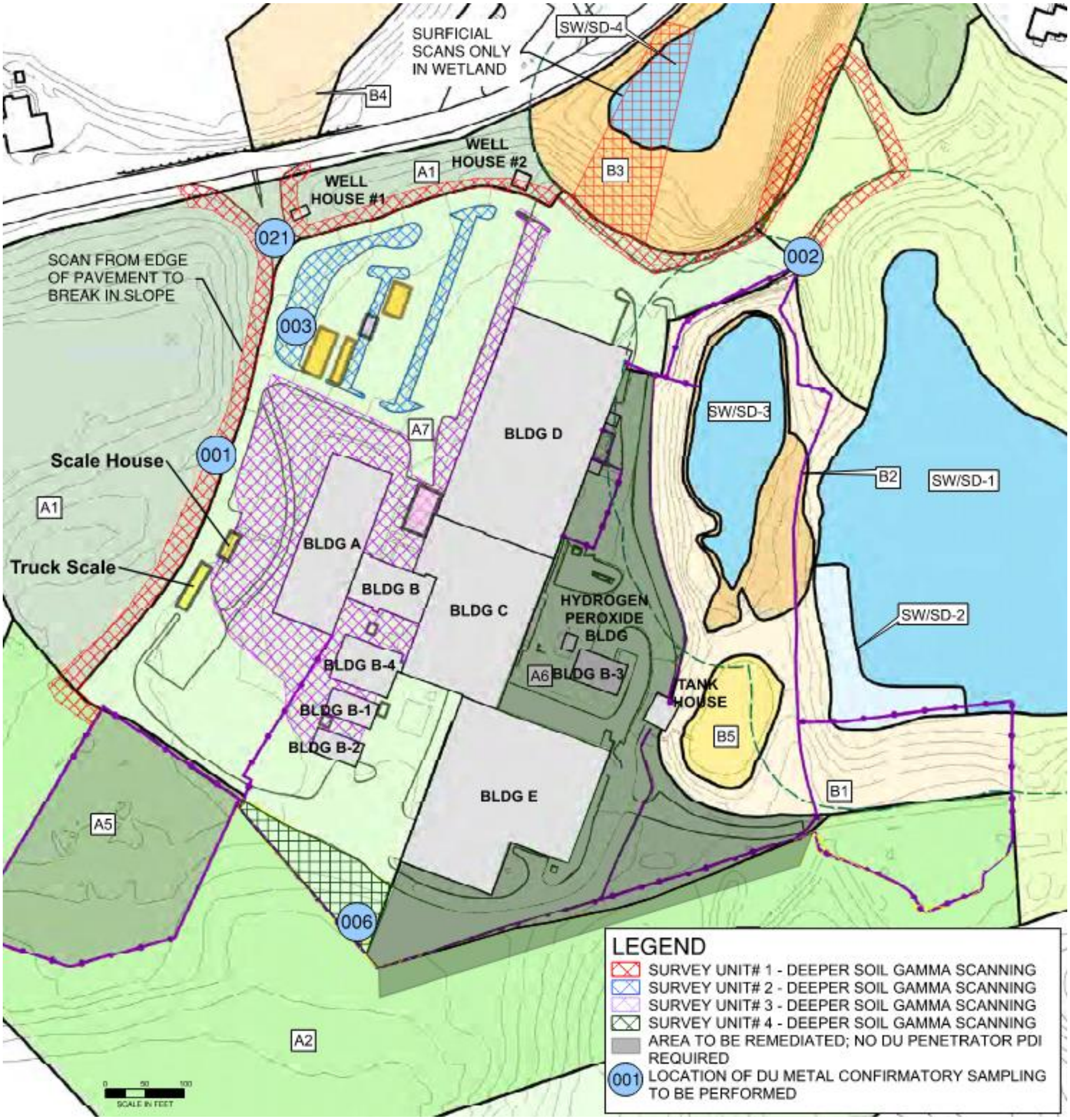
The scope of work is as follows:

- Collect soil samples at previously remediated locations to confirm complete removal of DU penetrators/metal fragments and impacted soil to meet the Remedial Action Objectives (RAOs).
- Perform DU gamma walkover survey of surficial soil to evaluate the presence of DU penetrators/metal fragments.
- As needed, perform confirmatory sampling at locations where DU metal fragments are found.
- Repeat gamma walkover surveys and removal of impacted soil until no consistently elevated measurements are noted.

4 PROCEDURES

4.1 Confirmatory Sampling at Locations 001, 002, 003, 006, and 021

During the NTCRA, DU penetrators were removed from locations 001, 002, 003, 006, and 021 as shown on the plan below. Horizontal and vertical soil samples will be collected from these locations to confirm removal of remaining metal fragments or impacted soil.


SURFICIAL SCANS ONLY IN WETLAND
SW/SD-4
B4
WELL HOUSE #2
A1
WELL HOUSE #1
B3
021
002
SCAN FROM EDGE OF PAVEMENT TO BREAK IN SLOPE
003
SW/SD-3
A7
BLDG D
001
Scale House
B2
SW/SD-1
A1
BLDG A
Truck Scale
BLDG B
BLDG C
HYDROGEN PEROXIDE BLDG
SW/SD-2
BLDG B-4
A6
BLDG B-3
TANK HOUSE
BLDG B-1
B5
BLDG B-2
B1
A5
BLDG E
006
A2
0 50 100
SCALE IN FEET
LEGEND
SURVEY UNIT# 1 - DEEPER SOIL GAMMA SCANNING
SURVEY UNIT# 2 - DEEPER SOIL GAMMA SCANNING
SURVEY UNIT# 3 - DEEPER SOIL GAMMA SCANNING
SURVEY UNIT# 4 - DEEPER SOIL GAMMA SCANNING
AREA TO BE REMEDIATED; NO DU PENETRATOR PDI REQUIRED
001 LOCATION OF DU METAL CONFIRMATORY SAMPLING TO BE PERFORMED

At each of the former DU penetrator/metal fragment soil removals performed during the NTCRA, four discrete samples will be collected approximately 90 degrees from each other, each approximately 1 foot away from edge of the soil removal area. A discrete vertical sample will also be collected at the bottom of the former removal.

Samples will be collected by compositing the volume of the discrete sample in a stainless-steel bowl or aluminum pan. The volume of collected material will be stirred to homogenize the sample and then placed in appropriate glassware for submission to the laboratory.

In addition to uranium, samples will be submitted for laboratory analysis of all site COCs, including polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs) (benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, and indeno(1,2,3-cd)pyrene), arsenic, and thorium. The applicable analytical methods are provided below:

- PCBs by EPA Method 8082 with Soxhlet Extraction
- PAHs by EPA Method 8270
- Uranium, Thorium, and Arsenic by EPA Method 6020

If necessary, following review of the results from the sampling program described above, additional sampling may need to be performed to excavate the remaining DU penetrator/metal fragment impacted soil. An additional 1 to 2 feet of soil horizontally from the impacted sidewall or an additional 6 inches vertically from the impacted bottom will be excavated, and then the newly exposed sidewall or bottom will be resampled for site COCs.

4.2 DU Gamma Walkover Surveys

The DU gamma walkover survey is planned to be completed in areas of the site where remedial excavations are not already planned. This area will be divided into 4 survey units (SU# 1, 2, 3, and 4) as shown on the figure above. The DU penetrators and metal fragments pose the challenge that if they are buried deeper than a few inches, they will not be detectable by typical gamma scanning. The approach for detecting DU penetrators and metal fragments in soil deeper than 6 inches is to remove the overlying soil to create a new soil surface and then scan the new soil surface with the NaI detector.

Prior to completing the surveys, survey grids will be created for the survey units shown above. The gamma walkover surveys are planned to be completed with a shielded 2x2 sodium iodide (NaI) detector coupled with a submeter accuracy GPS. Gamma walkover surveys will be performed by walking in a line within the survey unit/survey grid. The speed of the walkover survey will be approximately 0.5 meters per second while moving the detector in a serpentine fashion, as close to the ground surface as possible (no more than 4 inches above ground surface). The gamma walkover survey will pause at locations with elevated rates to collect more data in the vicinity to resolve if truly elevated. Locations with NaI measurements consistently above the action level (2x instrument background) will be marked for additional investigations.

Within the survey units, the proposed scope is first to perform a gamma walkover survey of the existing soil surface. If no elevated NaI measurements are recorded in the existing surficial soil within the survey units, then the top 6 inches will be scraped back (and set aside for use in backfilling after survey is complete), and another gamma walkover survey of the newly exposed surface soil will be performed.

Due to the field conditions present in the area shown as SU# 1, the gamma walkover surveys may be limited in this survey unit. SU# 1 is located along the edge of the pavement and existing fence line and is shown in red hatching in the figure above. The gamma walkover survey will be conducted from the edge of the pavement to the break in slope, which varies from 3 to 10 feet along the fence. The survey limits also show an area from the edge of the pavement along a steep slope to the northern wetlands. Gamma walkover surveys along the slope and wetland area are proposed to be surficial scans only depending on field conditions.

4.3 Investigation of Elevated NaI Measurements

If DU penetrators and/or metal fragments and associated soil are identified, the metal and visibly impacted soil will be excavated and containerized. Additional investigations will be performed to identify the source of the contamination in soil. These investigations will involve hand excavation and/or soil sieving to retrieve and dispose of any DU penetrator/metal fragments. The soil surrounding the metal fragment(s) and any visibly impacted soil will be removed. Confirmatory soil sampling of the excavation will be performed as described in Section 4.1.

After removal and confirmatory sampling, another 6-inch lift of soil will be excavated, and a gamma walkover survey will be completed. The process of scanning, removal, and confirmatory sampling will be repeated until no elevated NaI measurements due to DU penetrators/metal fragments are identified.

4.4 IDW Management

Investigation-derived waste (IDW) generated during the delineation sampling may include DU metal fragments and surrounding impacted soil, which will be containerized, stored on-site, and shipped off-site for disposal.

Un-impacted, stockpiled soil to be used as backfill will be placed back within the exploration locations.

5 REPORTING

The status of this PDI and potential results will be provided to EPA during routine project meetings and status reports. Results and the outcome of the PDI will be provided in the PDI Evaluation Report and incorporated into the 30% RD report.

ATTACHMENT 3 - PDI SSS-3: SUBSLAB SOIL CHARACTERIZATION

1 INTRODUCTION

This Pre-Design Investigation (PDI) activity for site-wide soils and sediments (SSS) will investigate the limits of site Constituents of Concern (COCs) below the concrete slabs of the former buildings related to possible leaks from utilities. The results of PDI SSS-3 will be used to design remedial investigations in conjunction with removal of the building slabs.

2 OBJECTIVES

The objectives for performing the testing described in this PDI are as follows:

- Collect soil samples at depth in four locations under the concrete slab of the former buildings in areas identified as having utilities.
- Evaluate the extent of impacted soil below the building slabs related to possible leaks from utilities.
- Design a soil management plan for removing impacted soil in conjunction with removal of the concrete slabs and utilities based on the results of the sampling investigations.

The scope of work for this PDI includes collecting soil samples for site COCs as described below.

3 SCOPE OF WORK

At four locations below the concrete slab of the former building, soil sampling will be conducted to depths of 26 feet below ground surface. Prior to drilling, a concrete coring subcontractor is planned to core through the existing concrete slab at four locations to facilitate collection of soil samples below the existing slab. Samples are planned to be collected using a direct push (Geoprobe) or hollow-stem auger drill rig.

4 PROCEDURES

The procedures described below are augmented by the field sampling and laboratory procedures described in the Field Sampling Plan (FSP) and Quality Assurance Project Plan (QAAP).

4.1 Concrete Coring of the Former Building Slabs

In order to facilitate collection of samples below the former building slabs without compromising the slab or disturbing the soil beneath, a concrete coring subcontractor will be employed to core through the slab. This will allow a drill rig to access the soil beneath the slab without damaging the drilling equipment or without the need to remove sections of concrete slab and disturb the soil beneath. It will also provide further detail about the thickness of the concrete slab at the specified locations. The contractor will core through the concrete slab to create an approximately 4-inch diameter hole. The concrete core will be placed aside for appropriate disposal during future activities.

4.2 Subsurface Sampling

At the locations shown on the figure below, soil samples are planned to be collected using a direct push (Geoprobe) or hollow-stem auger drill rig. The drill rig will be advanced to a depth of 26 feet. The drill rig will utilize 2- or 4-feet sleeves to collect samples at the following depths: 4 to 6 feet, 6 to 8 feet, 8 to 10 feet, 10 to 12 feet, 12 to 14 feet, 14 to 16 feet, 16 to 18 feet, 18 to 20 feet, 20 to 22 feet, 22 to 24 feet, and 24 to 26 feet. Samples will be collected by compositing the entire length of the proposed sample in a stainless-steel bowl or aluminum pan. The volume of collected material will be stirred to homogenize the sample and then placed in appropriate glassware for submission to the laboratory. Samples will be analyzed for uranium, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs) (benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, and indeno(1,2,3-cd)pyrene), arsenic, and thorium.

Project	Nuclear Metal Superfund Site, Concord, MA	Date	4 September 2020
Client	Remedial Design Work Plan	Page	3 of 6

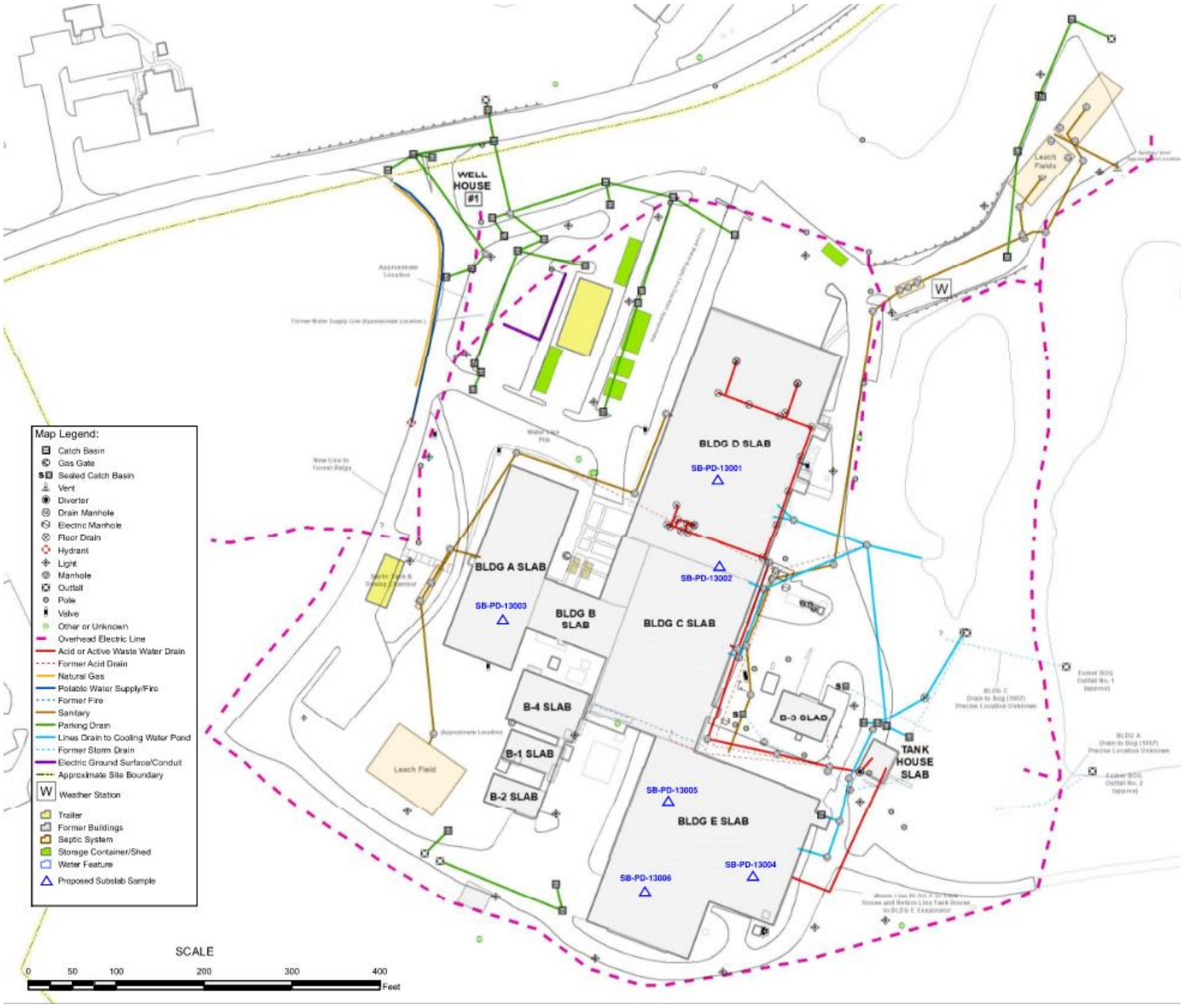


Table 1 – Proposed Subslab Sampling Plan

Sampling Location	Sample Location ID Number	Medium/ Matrix	Depth (ft)[1]	Analytical Parameters[2]
SB-PD-13001	-004-DATE	Soil	4-6	Uranium, PCBs, PAHs, arsenic, thorium
	-006-DATE		6-8	
	-008-DATE		8-10	
	-010-DATE		10-12	
	-012-DATE		12-14	
	-014-DATE		14-16	
	-016-DATE		16-18	

Sampling Location	**Sample Location ID Number**	**Medium/ Matrix**	**Depth (ft)**[1]	**Analytical Parameters**[2]
	-018-DATE		18-20	
	-020-DATE		20-22	
	-022-DATE		22-24	
	-024-DATE		24-26	
SB-PD-13002	-004-DATE	Soil	4-6	Uranium, PCBs, PAHs, arsenic, thorium
	-006-DATE		6-8	
	-008-DATE		8-10	
	-010-DATE		10-12	
	-012-DATE		12-14	
	-014-DATE		14-16	
	-016-DATE		16-18	
	-018-DATE		18-20	
	-020-DATE		20-22	
	-022-DATE		22-24	
	-024-DATE		24-26	
SB-PD-13003	-004-DATE	Soil	4-6	Uranium, PCBs, PAHs, arsenic, thorium
	-006-DATE		6-8	
	-008-DATE		8-10	
	-010-DATE		10-12	
	-012-DATE		12-14	
	-014-DATE		14-16	
	-016-DATE		16-18	
	-018-DATE		18-20	
	-020-DATE		20-22	
	-022-DATE		22-24	
	-024-DATE		24-26	
SB-PD-13004	-004-DATE	Soil	4-6	Uranium, PCBs, PAHs, arsenic, thorium
	-006-DATE		6-8	
	-008-DATE		8-10	
	-010-DATE		10-12	
	-012-DATE		12-14	
	-014-DATE		14-16	
	-016-DATE		16-18	
	-018-DATE		18-20	

Sampling Location	**Sample Location ID Number**	**Medium/ Matrix**	**Depth (ft)[1]**	**Analytical Parameters[2]**
	-020-DATE		20-22	
	-022-DATE		22-24	
	-024-DATE		24-26	
SB-PD-13005	-004-DATE	Soil	4-6	Uranium, PCBs, PAHs, arsenic, thorium
	-006-DATE		6-8	
	-008-DATE		8-10	
	-010-DATE		10-12	
	-012-DATE		12-14	
	-014-DATE		14-16	
	-016-DATE		16-18	
	-018-DATE		18-20	
	-020-DATE		20-22	
	-022-DATE		22-24	
	-024-DATE		24-26	
SB-PD-13006	-004-DATE	Soil	4-6	Uranium, PCBs, PAHs, arsenic, thorium
	-006-DATE		6-8	
	-008-DATE		8-10	
	-010-DATE		10-12	
	-012-DATE		12-14	
	-014-DATE		14-16	
	-016-DATE		16-18	
	-018-DATE		18-20	
	-020-DATE		20-22	
	-022-DATE		22-24	
	-024-DATE		24-26	

NOTES:

1. Sample depths may be adjusted based on visual and/or olfactory evidence.
2. Analytical methods:
   a. Uranium, Thorium, and Arsenic by EPA Method 6020
   b. PCBs by EPA Method 8082
   c. PAHs by EPA Method 8270

4.3 IDW Management

Investigation-derived waste (IDW) generated during the delineation sampling will include soil and concrete cuttings from subsurface explorations. Excess soil will be placed back within the exploration borehole. Concrete cores will be managed for off-site disposal with future slab demolition. Concrete holes will be patched to prevent infiltration.

5 REPORTING

The status of this PDI and potential results will be provided to EPA during routine project meetings and status reports. Results and the outcome of the PDI will be provided in the PDI Evaluation Report and incorporated into the 30% RD report.

ATTACHMENT 4 - PDI SSS-4: COOLING POND, SPHAGNUM BOG, AND LANDFILL EXCAVATION EVALUATIONS

Project	Nuclear Metal Superfund Site, Concord, MA	Date	4 September 2020
Client	Remedial Design Work Plan	Page	1 of 8

1 INTRODUCTION

The Pre-Design Investigation (PDI) activity for site-wide soils and sediments (SSS) will investigate the characteristics of the Cooling Pond, the Sphagnum Bog, the Landfill, and the Gabion Wall. The results of PDI SSS-4 will be used to design the remedial excavations at each area.

The selected remedy outlined in the Record of Decision (ROD) includes excavation of approximately 82,500 cubic yards of material from non-Holding Basin areas of the site which have been impacted by DU, PCBs, PAHs, and copper. Areas requiring excavation due to concentrations of contaminants of concern include the Landfill, the edges of the Sphagnum Bog, and the Cooling Pond. Maintaining stable slopes with adequate safety factors during remedial excavations is critical for performing the remedial excavations outlined in the ROD and we anticipate that support of excavation measures such as sheeting may be required in some locations.

The Landfill is the site of former buried debris as defined in the RI. A previous survey was conducted during the Remedial Investigation (RI) at a portion of the landfill to evaluate for buried debris. This PDI will define the limits of the buried debris within the landfill to be removed during remedial excavations and will extend to the area outside of the fence limits to the east of the landfill where remedial excavations are planned.

The Cooling Pond is an approximate 0.6-acre depression, and approximately 2 to 3 feet of contaminated material will be excavated from the Pond during remedial activities. Following the remedial excavations at the Cooling Pond, the Pond will be restored as a wetland. Information on the interaction between groundwater and surface water at the Cooling Pond is needed to confirm that sediments imported for restoration will not be re-contaminated by site groundwater. Additionally, a Gabion Wall is present to the north of the Cooling Pond which currently poses a risk of failure during excavation of materials within the Cooling Pond and the former septic fields to the north of the wall. Information on slope stability is needed to design the remedial excavations.

The Sphagnum Bog is a 3.5-acre palustrine acidic wetland composed of sphagnum moss and scattered stunted or immature growth of tamarack growing over a layer of acidic peat. Other proposed restoration areas include a transitional shrub zone, a perimeter zone with standing water and cattail growth, and other herbaceous wetland species. Some sediment removal is planned within the bog to meet cleanup levels outlined in the ROD. Wetland restoration is planned to follow the remedial excavations at the southwest area of the Bog, and detailed field delineation and inventory of species is required to develop a restoration plan. The Sphagnum Bog has no inlets or outlets and receives the bulk of its moisture from precipitation and a limited area of direct surface run-off. The wetland restoration plans for the Cooling Pond and the Sphagnum Bog will be designed to fully restore all wetland resource areas and habitat types in-place and in-kind.

2 OBJECTIVES

The objectives for performing the testing described in this PDI are as follows:

- Assess the potential for and delineate the limits of buried debris within the remedial excavation areas at the Landfill and within the former septic fields.
- Evaluate the slope stability of several areas proposed for remedial excavation areas and of the Gabion Wall.
- Evaluate the groundwater-surface water interaction and groundwater-sediment relationship at the Cooling Pond.
- Characterize and inventory existing wetland conditions at the Sphagnum Bog and Cooling Pond.

The results of this PDI will support the design of remedial excavations and inform the wetland restoration requirements following the remedial excavations.

3 SCOPE OF WORK

The scope of work for this PDI includes a geophysical survey, collection of field data to support the slope stability analysis, and collection of field data on shallow geology along site slopes, sediment and groundwater chemistry at the Cooling Pond, and information on the inventory and limits of existing wetland conditions at the Cooling Pond and Sphagnum Bog.

4 PROCEDURES

The procedures described below are augmented by the field sampling and laboratory procedures described in the FSP and QAAP.

4.1 Geophysical Survey

Geophysical surveys will be completed in two areas of the site, as shown on Figure 4. A geophysical survey will be performed within the landfill area and within the former septic system area north of the Cooling Pond. A geophysical survey was performed by MACTEC at the landfill in conjunction with the Remedial Investigation (RI) but was only performed within the limits of the fencing at the time of the survey and identified some anomalies which may have been due to the metal fencing. This PDI will confirm the results documented in the RI report, and extend the survey to outside the limits of the fence. The fence will be removed, and some vegetation may need to be cleared prior to the survey.

The second geophysical survey will be performed within the former septic fields. This will be a due diligence survey to confirm the limits of the septic fields, and to evaluate if there are other buried debris or associated structures in the area. Subsurface components at the septic fields may include steel pipes, concrete septic tanks, concrete dosing tanks, other precast leaching structures, and other metallic waste materials may have been buried during the construction of the septic system. The former septic field area is currently paved with a driveway and parking lot.

The surveys will be completed by establishing a 10-foot by 10-foot reference grid within each survey area to be marked using spray paint or flagging. Perpendicular nodes will also be laid out with a theodolite or fiberglass measuring tape throughout the survey areas.

At each location, two methodologies will be used in the geophysical survey. An electromagnetic (EM) survey will be used to evaluate for debris. The EM survey is capable of detecting metal debris at depths of approximately up to 8 feet. EM devices proposed to be used in the survey include Radiodetection Model 7100, Genoics EM61, or Genoics EM31. Conductivity is logged in 0.5-second increments as the operator traverses the grid and annotates the data files. A Ground Penetrating Radar (GPR) survey will also be used, which is capable of identifying subsurface structures in greater detail at depths of up to approximately 15 feet. GPR devices proposed to be used in the survey include GSSI Model SIR-2000 or SIR-4000, with a 200 or 400 MHz radar antenna. Following the surveys, the EM data will be used to generate contour maps using Golden Software's *Surfer* program. GPR data interpretation will be performed using GSSI's *RADAN* software.

In addition to the EM and GPR surveys at the landfill, a total-field magnetic profiling is planned to distinguish any anomalies caused by ferrous metal or non-ferrous metal objects. The total-field profiling is performed with a Geometrics model G-858 magnetometer, which records magnetic data values at 0.5 seconds as the operator traverses the 10-feet grid. The magnetometer's software is used to interpolate distances for magnetic values between stations.

Approximate limits of the proposed survey areas are shown on Figure 4. The survey limits may be extended based on the initial field results.

4.2 Former Septic Field Test Pits

Following the geophysical survey at the former septic field area, up to 4 test pits will be excavated to confirm the presence and limits of the subsurface structures identified in the GPR and EM surveys. Test pits will be excavated to depths of approximately 8 to 10 feet using a track-mounted excavator.

Approximate locations of the proposed test pits are shown on Figure 4.

4.3 Soil Sampling

Up to one soil analytical sample will be collected from the test pits at the former septic field to confirm the limits of the septic field structures. Due to the purpose of the septic field as a common waste collection point for the site, the soil sample will be analyzed for the COCs outlined in the ROD, for soils and groundwater including:

- SVOCs
- VOCs
- Metals (Arsenic, Chromium, Thorium, Barium, Chromium, Cobalt, Copper, Iron, Manganese, Molybdenum
- PCBs
- Nitrate-N and Nitrite-N
- Uranium (total and U-238, U-235 and U-234)

4.4 Bog Sediment Investigation

Data is needed on the geotechnical properties of the Sphagnum Bog sediments in order to perform the slope stability analysis, support the wetland characterization, and to collect data to determine the excavation support that may be needed, if any, to remove the sediment required to be excavated. Details on sediment sampling methods for this PDI and for PDI HB-4 are included in the Site Wide Soils and Sediments Cooling Pond, Sphagnum Bog, Septic Field and Landfill Excavation Evaluations Implementation Plan in Attachment 6.

Up to 6 shallow hand probes will be advanced to gather data on the thickness of the sediment in the Bog, at locations shown on Figure 5. Specific data will be collected on the thickness and depths of the two distinct peat layers present in the Bog (the acrotelm and catotelm). The acrotelm is believed to be 12 to 20 inches thick overlying the catotelm layer. Up to 3 ft of the sediment is proposed to be excavated and there is likely temporary sheeting necessary to toe into the soil underlying the peat; therefore the thickness of the peat along the edge of the proposed excavation corresponds to the proposed hand probes shown on Figure 5.

Additionally, up to 6 torvane tests will be performed in the shallow hand probes to evaluate the shear strength of the bog sediments if the material is suitable for a torvane test. It is possible that the peat will be too fibrous to obtain in-situ measurements.

4.5 Slope Stability Analysis

Slope stability analyses will be performed for the area above the Gabion Wall, the side slopes of the Cooling Pond, the Landfill, and the Bog, as well as the interface between the Landfill and the Bog. The purpose of the slope stability analysis at these locations is to design methods of remedial excavations and evaluate the need for support of excavation within and between each remedial area.

Slope stability analysis will be performed using the *Slide2* 2018 software by Rocscience. *Slide2* is a two-dimensional equilibrium slope stability program for evaluating factors of safety of circular and non-circular failure in soil or rock slopes. The program analyzes the stability of slip surfaces using vertical or non-vertical slice limit equilibrium methods under specified boundary conditions.

The slope stability model will be built using topographic conditions and shallow geologic profiles observed during the subsurface explorations performed in this PDI. Properties of subsurface material, such as unit weight, strength, cohesion, and friction angle, will be estimated based on field observations, new test borings associated with other PDIs, previous test borings, and torvane testing performed in this PDI.

The model will evaluate the slope stability of each area under current conditions, as well as proposed conditions, such as during remedial excavations or with support of excavation measures. Each model will evaluate conditions for static, pseudo-static, and post-earthquake conditions.

4.6 Piezometer Installation

To evaluate hydrogeologic conditions at the Cooling Pond, up to 12 piezometers will be installed in pairs of two to evaluate shallow and deep conditions. The proposed locations of the piezometers are shown on Figure 5. The proposed piezometers are manufactured by Solinst and will be hand-driven using a Manual Slide Hammer. Drive-point piezometers will be constructed of 1.5-inch diameter stainless steel riser with a 6-inch long screen and will be installed in pairs. At each of the six locations at the Cooling Pond, one piezometer will be installed 3 feet into sediment and the other will be installed 6 feet into sediment/sand. A summary of proposed piezometers is included below.

Piezometer	Well Depth Below Sediment Surface (ft)	Sediment Analytes	Groundwater Analytes
HA20-PZ-1S	3	CVOCs TOC Uranium Copper	CVOCs TOC Uranium Copper
HA20-PZ-1D	6		
HA20-PZ-2S	3		
HA20-PZ-2D	6		
HA20-PZ-3S	3		
HA20-PZ-3D	6		
HA20-PZ-4S	3		
HA20-PZ-4D	6		
HA20-PZ-5S	3		
HA20-PZ-5D	6		
HA20-PZ-6S	3		
HA20-PZ-6D	6		

Up to four rounds of head measurements will be collected from the 12 piezometers, which will provide seasonal variation of water levels. Information on head differentials between the shallow and deep sediment wells will inform our understanding of the interaction between groundwater and surface water.

This data will be used to develop a cross section and identify lateral and vertical gradients at the Cooling Pond.

Locations of proposed piezometers are shown on Figure 5.

4.7 Groundwater Sampling

Up to 12 groundwater samples (one from each newly installed piezometer) will be collected from the Cooling Pond. Groundwater quality data will be used in conjunction with head measurements and sediment quality data to evaluate the potential for contaminants to transport between sediment and groundwater. The initial round of groundwater sampling will be conducted once all the piezometers are installed so the groundwater and sediment samples are collected within days of each other to correlate the groundwater and sediment concentrations. Quarterly sampling of each piezometer will be conducted to evaluate seasonal variation of the chemistry within the groundwater and surface water. Sampling of the piezometers will be conducted quarterly for 1-year starting with the initial round of sampling.

Sampling will be performed using low-flow methodology as outlined in the EPA Low-Stress (Low-Flow) Standard Operating Procedure EQASOP-GW4, as summarized in NMI-GW-010 SOP. Field instruments will be inspected and calibrated at the beginning of each day and checked during field activities to verify performance. Instrument specific calibration procedures will be performed in accordance with the instrument manufacturer’s requirements.

During low-flow purging, a multi-parameter meter will be used to measure pH, specific conductivity, turbidity, dissolved oxygen, oxidation reduction potential (ORP) and temperature. Readings will be collected at 5-minute intervals and recorded on field logs. Once parameters are stable, the samples will be collected into laboratory provided glassware.

Groundwater samples will be submitted to a National Environmental Laboratory Accreditation Program (NELAP) accredited laboratory for analysis of chlorinated volatile organic compounds (CVOCs), uranium, copper, and total organic carbon (TOC). Uranium is the primary contaminant of concern in groundwater at the Cooling Pond. The addition of copper, chlorinated VOCs, and TOC data will be used to calculate the sorption from groundwater to sediment. The chlorinated VOCs include 1,1-Dichloroethane (DCA), trichloroethene (TCE), tetrachloroethene (PCE), and vinyl chloride. In addition, the groundwater COCs 1,4-Dioxane , bis(2-Ethylhexyl) phthalate, arsenic, barium, chromium, cobalt, copper, iron, manganese, molybdenum, uranium, and nitrate will be included in the groundwater and sediment testing. The analyte list is consistent with the Groundwater Cleanup Levels listed in Table L-1 of the ROD.

4.8 Sediment Sampling

Up to 12 sediment samples will be collected at the locations of the proposed piezometers shown on Figure 5, within the footprint of the Cooling Pond. Sediment samples will be collected from the depth intervals where the well screen is installed at each piezometer location. The Implementation Plan in Attachment 6 includes details of sediment sampling methods that will depend on the consistency and depth below standing water at the time of sampling. The types of sampling tools and the hierarchy of tool selection is discussed in the Implementation Plan. Collocating the sediment and groundwater samples allows for an evaluation of potential for contaminants to transport between sediment and groundwater.

Sediment samples will be submitted to a National Environmental Laboratory Accreditation Program (NELAP) accredited laboratory for analysis of chlorinated volatile organic compounds (CVOCs), uranium, copper, and total organic carbon (TOC). Uranium is the primary contaminant of concern in groundwater at the Cooling Pond, and the other analytes tested will be used to calculate the sorption from groundwater to sediment.

4.9 Wetland Characterization

This PDI will collect the information needed to characterize current conditions at the Cooling Pond and the Bog in order to design the wetland restoration plan following the remedial excavations in each area.

This investigation includes compiling an inventory of plant species growing within the habitat zones, and delineation of resource areas and habitat types, including vegetated border areas, banks, and transitional zones which may be disturbed during remedial activities. Observations will be documented on the dominant and common species within each habitat zone and supporting figures and field notes will be annotated with current conditions.

The wetlands mapping and evaluation of the functions and values will be conducted as follows:

- Wetlands will be delineated according to the methodology required per 310 CMR 10.00 as described in *Delineating Bordering Vegetated Wetlands Under the Massachusetts Wetlands Protection Act* (MassDEP, 1995).

- Wetland functions and values will be assessed according to the methodology described in *The Highway Methodology Workbook Supplement: Wetland Functions and Values – A Descriptive Approach* (U.S. Army Corps of Engineers, New England District, September 1999).

Data from the bog sediment depths will be used with species inventory and delineation information collected in this activity to develop a final restoration approach, including soil specifications, planting plan, and related details.

4.10 IDW Management

Investigation-derived waste (IDW) generated during the work described herein will include soil cuttings from shallow subsurface explorations. Excess soil will be placed back within the exploration borehole.

5 REPORTING

The status of this PDI, and potentially results, will be provided to EPA during routine project meetings and status reports. Results and the outcome of the PDI will be incorporated into a PDI Evaluation Report and the 30% RD report.

ATTACHMENTS
SECTION 1 – Piezometer Specifications

Section 4
PDI SSS-4 Specifications

Solinst®

Drive-Point Piezometers

Model 615 Data Sheet

Stainless Steel Drive-Point Piezometers

Model 615

The Model 615 Drive-Point Piezometer is designed as an affordable method to monitor shallow groundwater and soil vapor in suitable conditions.

The Drive-Points attach to inexpensive 3/4" (20 mm) NPT stainless steel drive pipe. The Drive-Points are designed for single use installations, and not for removal and reuse. Solinst Drive-Point Piezometers are most often installed as permanent well points. They can also be used for temporary, short term monitoring applications.

Higher quality samples can be obtained when polyethylene or PTFE-lined tubing is attached to the stainless steel drive-point. Groundwater sampling and hydraulic head measurements can be taken within the tubing using small diameter equipment, as described overleaf.

Solinst Drive-Point Piezometers can be driven into the ground with any direct push or drilling technology, including the Manual Slide Hammer shown at right. To avoid clogging or smearing of the screen during installation, a shielded version is also available.

Installing Piezometers with a Manual Slide Hammer

Get Quote | More Info

Model 615 Drive-Point and Shielded Drive-Point Piezometer

Applications

- Groundwater sampling, including VOCs
- Water level monitoring
- Base flow monitoring in stream beds
- Contaminant plume delineations
- Soil gas sampling
- UST monitoring
- Low cost and minimal disturbance site assessment
- Sparge points

High Quality Samples

Model 615 Drive-Point Piezometers have a stainless steel, 50 mesh cylindrical filter-screen, within a 3/4" (20 mm) stainless steel drive-point body, screen support and an optional fitting for attachment of sample tubing.

615 N

The 615 N or 615 SN, designed without a tubing barb, is to be used for water level measurements. This saves money and provides better access for Water Level Meters.

615

The 615 or 615 S has an inner barbed fitting for 5/8" OD x 1/2" ID (16 mm x 12 mm) LDPE or PTFE-lined sample tubing. This prevents sample water from contacting the extension rods, and maintains high sample integrity, even when inexpensive galvanized steel extensions are used.

615 C

The 615 C is ideal for soil vapor sampling. Where an air-tight connection is most desirable, the compression fitting option allows users to attach 1/4" (6 mm) sample tubing directly to the top of the screened portion of the drive-point.

The 615 S and 615 SN shielded drive-points have a single use, 1-1/2" (38 mm) dia. shield to avoid smearing and plugging of the screen during installation. The strengthened connector at the top of the drive-point acts as an annular seal, which avoids contamination from higher levels in the hole.

Solinst®

Drive-Point Piezometers

Sampling Within Narrow Diameters

Direct push sampling has quickly become a popular way to obtain groundwater samples. However, sampling within drive-points requires a narrow diameter sampler. Solinst offers several options for this specific sampling application.

Peristaltic Pump, Model 410

The Peristaltic Pump uses the suction lift principle. Suitable for 1/4" (6 mm) ID or larger diameters. The Peristaltic Pump provides a regulated and steady flow. It will lift water up to 32 ft. (10 m) at sea level.

Mini Inertial Pump, Model 404

The Mini Inertial Pump consists of a check valve and tubing that is rapidly raised and lowered to lift a sample. The Mini Inertial Pump suits wells as narrow as 3/8" (9.5 mm) ID and works to depths of 100 ft. (30 m).

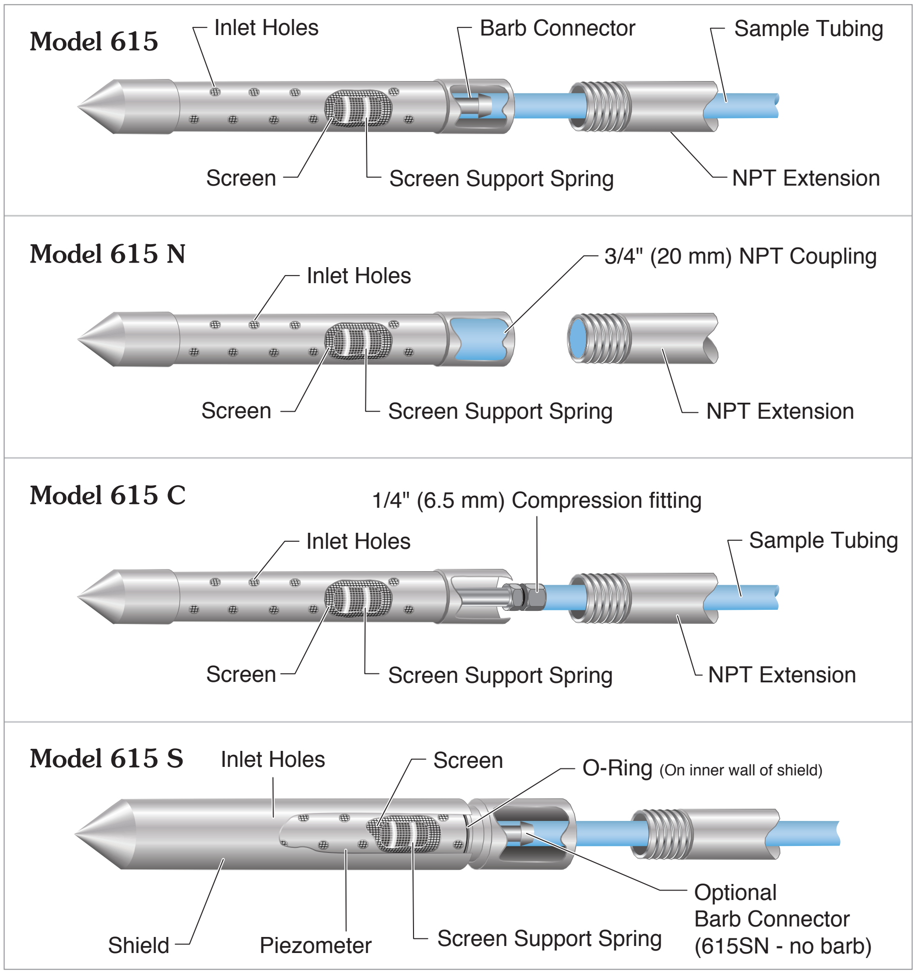
Miniature Point Source Bailer, Model 429

The 1/2" (12 mm) dia. stainless steel bailer works very well in the 615 N or 615 SN. The bottom emptying device permits a regulated, steady flow.

Hydraulic Head

Water levels can be measured in most of the Drive-Points described, using a Solinst 101 Water Level Meter, or 102 or 102M Mini Laser Marked Coaxial Cable Water Level Meter. 1" to 3/4" reducer couplings are available for installing a Levelogger in a section of 1" extension pipe (NPT and BSPT options).

Stainless Steel Drive-Point Piezometers



Solinst Drive-Point Piezometers are available in five different configurations; the 615 with a barbed fitting, the 615 N with no barbed fitting, the 615 C with a compression fitting, the 615 S with a barbed fitting and shield, and the 615 SN with a shield and no barbed fitting.

Manual Slide Hammer

To install Solinst Drive-Point Piezometers inexpensively, the Manual Slide Hammer can be used. The 21 lb (9.5 kg) slide hammer and all other equipment can easily be transported in a car or truck to most sites.

A heavy duty drive head is used, on which the slide hammer impacts, and a tubing by-pass ensures that the tubing does not get damaged during installation.

Accessories

Solinst supplies 3/4" (20 mm) NPT Delrin caps, and stainless steel couplings and extensions. These accessories can also be locally sourced at plumbing and hardware stores.

Depth Limitations

Drive-point Piezometers are not suitable for all sites. The depth limitations vary with soil conditions and the drive method used.

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For further information contact: Solinst Canada Ltd.
Fax: +1 (905) 873-1992; (800) 516-9081 Tel: +1 (905) 873-2255; (800) 661-2023
35 Todd Road, Georgetown, Ontario Canada L7G 4R8
Web Site: www.solinst.com E-mail: instruments@solinst.com

Solinst®

ATTACHMENT 5 - PDI SSS-5: BORROW SOURCE AND REGRADING EVALUATION

Project	Nuclear Metal Superfund Site, Concord, MA	Date	4 September 2020
Client	Remedial Design Work Plan	Page	1 of 4

1 INTRODUCTION

The Pre-Design Investigation (PDI) activity for site-wide soils and sediments (SSS) will investigate chemical and geotechnical properties of on-site soil that could be used as backfill. The results of PDI SSS-5 will be used to determine the limits and volume of on-site material that is suitable for reuse as backfill.

The selected remedy outlined in the Record of Decision (ROD) includes excavation of approximately 82,500 cubic yards of material for disposal at an off-site disposal facility. The remedial excavations will need to be backfilled with clean material from an off-site borrow source or from on-site material. We estimate that up to 50,000 cubic yards of material can be backfilled using on-site material from the hill side within the northwest area of the site. Based on preliminary cut and fill calculations, a total of approximately 20,000 to 60,000 cubic yards of material can feasibly be excavated from the area as shown on Figure 4. The use of on-site material as backfill is cost-effective and beneficial for reducing on-site and local traffic from hauling trucks importing and exporting material.

We estimate that topsoil and/or unsaturated granular fill or natural material may be suitable for reuse on-site as backfill. Based on existing information, we estimate that the groundwater table is located at approximately El. 130 (NGVD). Existing grades within the area proposed for excavation and backfill range from El. 190 to El. 195.

2 OBJECTIVES

The objectives for performing the testing described in this PDI are as follows:

- Characterize the chemical and geotechnical properties of on-site material proposed for reuse as backfill.
- Delineate the horizontal and vertical limits of material that is chemically and geotechnically suitable for reuse as backfill and can be excavated and graded to meet future uses of the Property.
- Estimate the proposed volume of on-site material that is suitable for reuse as backfill.

The results of this PDI will define the limits and volume of on-site material which may be used as borrow material for backfilling the remedial excavations.

3 SCOPE OF WORK

The scope of work for this PDI includes a series of soil borings, chemical analysis of soil samples for site COCs, geotechnical analysis of the soil samples for suitability of compaction and backfilling, and determining the range of groundwater elevations within the borrow source area, as described below.

4 PROCEDURES

4.1 Soil Borings

To evaluate suitability of on-site material for reuse as backfill, up to 5 borings will be advanced to depths of approximately 75 to 80 feet using drive and wash drill methods in a 4-inch diameter borehole. Overburden soils will be logged continuously using standard split-spoon sampling as temporary casing is set. Soil density will be determined at each strata encountered and samples will be collected for geotechnical laboratory testing. Three of the borings will be completed as observation wells and the other two borings will be backfilled with cuttings and grouted to ground surface. It is estimated that groundwater is approximately El. 130 and the wells will be set to help determine seasonal high groundwater elevations so the borrow source is not excavated below groundwater and that at least 10 ft. of separation between finished grade and groundwater is provided.

Locations of the proposed borings are shown on Figure 4. A summary of proposed borings, monitoring wells, and soil sampling is described below.

Boring/Well	Est. GS El. (NGVD)	Boring Depth (ft)	Well Type/Screen Strata	Est. Top of Screen El. (NGVD)	Soil Analytes
HA20-B201(OW)	194	80	2" PVC - Overburden, Sand/Gravel	130	Benzo(a)anthracene Benzo(a)pyrene Benzo(b)fluoranthene Ideno(1,2,3-cd)pyrene PCBs Arsenic Uranium Thorium
HA20-B202(OW)	193	80	2" PVC - Overburden, Sand/Gravel	125	
HA20-B203	193	80	N/A	N/A	
HA20-B204	193	80	N/A	N/A	
HA20-B205(OW)	191	80	2" PVC - Overburden, Sand/Gravel	120	

4.2 Installation of Observation Wells

Observation wells will be installed in 3 completed boreholes. Observation wells will be used to gather data on water levels within the proposed borrow source area. Wells will be constructed with 2-inch machine-slotted PVC screen and 2-inch PVC riser pipe. The location of the well screen, screen slot size, and filter pack will be determined based on field conditions.

Following the installation, observation wells will be developed in accordance with NMI-GW-002 Monitoring Well Development Operating procedure included in the Field Sampling Plan (FSP).

4.3 Soil Sampling

Up to 12 samples will be collected from discrete strata within the soil borings. Soil samples will be analyzed for site COCs and results will be compared against site-specific background criteria to evaluate suitability for on-site reuse. The frequency of sampling will be one sample every 5,000 cubic yards of borrow material. The samples collected and tested are intended to characterize the different layers of soil that are expected to be encountered for use as backfill. Samples will be collected within the top ft. to adequately characterize the topsoil or A-horizon soil. In addition, representative samples from the subsoil or B-horizon and from the parent geologic material (i.e. C-horizon) above the groundwater will be sampled and characterized for the suitability for use as backfill.

Samples with non-detections or detections below the Massachusetts Department of Environmental Protection criteria for background conditions and within the site-specific background criteria site COCs will be considered chemically suitable for reuse. The laboratory detection limits to meet these criteria is discussed in the QAPP.

4.4 Geotechnical Laboratory Testing

A sieve and hydrometer will be run on up to 6 samples of topsoil. A sieve and proctor will be run on up to 4 samples of other overburden material. Testing will be performed in accordance with the following ASTM International Standards:

- ASTM D6913/D6913M-17: Standard Test Methods for Particle Size Distribution (Gradation) of Soils Using Sieve Analysis
- ASTM D7928-17 Standard Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis
- ASTM D698: Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort

Copies of these standards are included in Section 1.

4.5 Volume Estimate

Data from the chemical and geotechnical testing will be used to evaluate which samples are representative of material suitable for reuse as backfill on-site. The results will be used to delineate the horizontal and vertical limits of material considered suitable for reuse on-site and estimate an approximate volume of material to be reused as backfill on-site.

4.6 IDW Management

Investigation-derived waste (IDW) generated during the work described herein will include soil cuttings from subsurface explorations. Excess soil will be placed back within the exploration borehole.

5 REPORTING

The status of this PDI, and potentially results, will be provided to EPA during routine project meetings and status reports. Results and the outcome of the PDI will be incorporated into a PDI Evaluation Report and the 30% RD report.

ATTACHMENTS
SECTION 1 – ASTM Standards

Section 5
PDI SSS-5 Standards

Designation: D6913/D6913M – 17

Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis[1]

This standard is issued under the fixed designation D6913/D6913M; 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.

INTRODUCTION

Although this test method has been used for many years, there are vast testing variations due to soil types and conditions. The test is more complicated and complex than would be expected. Multiple procedures are being presented along with new terminology. Although these procedures are not new, they will now be defined and explained. Some examples of these new terms are composite sieving, designated separating sieve and subspecimen. This test method outlines the majority of conditions and procedures but does not cover every conceivable variation or contingency. The table of contents in the Scope section is added to enable the user to easily find a specific topic or requirement. Only sections/subsections with titles are presented. Therefore, numbered subsections will not be continuous in some cases, as indicated in the Scope section.

1. Scope

1.1 Soils consist of particles with various shapes and sizes. This test method is used to separate particles into size ranges and to determine quantitatively the mass of particles in each range. These data are combined to determine the particle-size distribution (gradation). This test method uses a square opening sieve criterion in determining the gradation of soil between the 3-in. (75-mm) and No. 200 (75-µm) sieves.

1.2 The terms, soils and material, are used interchangeably throughout the standard.

1.3 In cases where the gradation of particles larger than 3 in. (75 mm) sieve is needed, Test Method D5519 may be used.

1.4 In cases where the gradation of particles smaller than No. 200 (75-µm) sieve is needed, Test Method D7928 may be used.

1.5 Typically, if the maximum particle size is equal to or less than 4.75 mm (No. 4 sieve), then single-set sieving is applicable. Furthermore, if the maximum particle size is greater than 4.75 mm (No. 4 sieve) and equal to or less than 9.5 mm (⅜-in sieve), then either single-set sieving or composite sieving is applicable. Finally, if the maximum particle size is equal to or greater than 19.0 mm (¾-in sieve), composite sieving is applicable. For special conditions see 10.3.

1.6 Two test methods are provided in this standard. The methods differ in the significant digits recorded and the size of the specimen (mass) required. The method to be used may be specified by the requesting authority; otherwise Method A shall be performed.

1.6.1 *Method A*—The percentage (by mass) passing each sieve size is recorded to the nearest 1 %. This method must be used when performing composite sieving. For cases of disputes, Method A is the referee method.

1.6.2 *Method B*—The percentage (by mass) passing each sieve size is recorded to the nearest 0.1 %. This method is only applicable for single sieve-set sieving and when the maximum particle size is equal to or less than the No. 4 (4.75-mm) sieve.

1.7 This test method does not cover, in any detail, procurement of the sample. It is assumed that the sample is obtained using appropriate methods and is representative.

1.8 *Sample Processing*—Three procedures (moist, air dry, and oven dry) are provided to process the sample to obtain a specimen. The procedure selected will depend on the type of sample, the maximum particle-size in the sample, the range of particle sizes, the initial conditions of the material, the plasticity of the material, the efficiency, and the need for other testing on the sample. The procedure may be specified by the requesting authority; otherwise the guidance given in Section 10 shall be followed.

1.9 This test method typically requires two or three days to complete, depending on the type and size of the sample and soil type.

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

Current edition approved April 15, 2017. Published May 2017. Originally approved in 2004. Last previous edition approved in 2009 as D6913 – 04(2009)$^{\varepsilon 1}$. DOI: 10.1520/D6913-17.

1.10 This test method is ***not*** applicable for the following soils:

1.10.1 Soils containing fibrous peat that will change in particle size during the drying, washing, or sieving procedure.

1.10.2 Soils containing extraneous matter, such as organic solvents, oil, asphalt, wood fragments, or similar items. Such extraneous matter can affect the washing and sieving procedures.

1.10.3 Materials that contain cementitious components, such as cement, fly ash, lime, or other stabilization admixtures.

1.11 This test method may not produce consistent test results within and between laboratories for the following soils and the precision statement does not apply to them.

1.11.1 Friable soils in which the sieving processes change the gradation of the soil. Typical examples of these soils are some residual soils, most weathered shales and some weakly cemented soils such as hardpan, caliche or coquina.

1.11.2 Soils that will not readily disperse such as glauconitic clays or some dried plastic clays.

1.11.3 To test these soils, this test method must be adapted, or altered, and these alterations documented. Depending on the design considerations, a specialized gradation-testing program could be performed. The alterations could require the washing and sieving procedures to be standardized such that each specimen would be processed in a similar manner.

1.12 Some materials that are not soils, but are made up of particles may be tested using this method. However, the applicable sections above should be used in applying this standard.

1.13 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026, unless superseded by this test method.

1.13.1 The procedures used to specify how data are collected/recorded and calculated in this standard are regarded as the industry standard. In addition, they are representative of the significant digits that generally should be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of these test methods to consider significant digits used in analysis methods for engineering design.

1.14 *Units*—The dimensional values stated in either SI units or inch-pound units are to be regarded as standard, such as 200-mm or 8-in. diameter sieve. Except, the sieve designations are typically identified using the "alternative" system in accordance with Practice E11, such as 3 in. and No. 200, instead of the "standard" system of 75 mm and 75 µm, respectively. Only the SI units are used for mass determinations, calculations, and reported results. However, the use of balances or scales recording pounds of mass (lbm) shall not be regarded as nonconformance with this standard.

1.15 A summary of the symbols used in this test method is given in Annex A1.

1.16 *This standard does not purport to address all of the safety concerns, if any, 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.*

1.17 *Table of Contents*—All tables and figures appear at the end of this standard.

Section

1.18 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C136 Test Method for Sieve Analysis of Fine and Coarse Aggregates
C702 Practice for Reducing Samples of Aggregate to Testing Size
D653 Terminology Relating to Soil, Rock, and Contained Fluids
D698 Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3))
D1140 Test Methods for Determining the Amount of Material Finer than 75-µm (No. 200) Sieve in Soils by Washing
D1557 Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))
D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
D2488 Practice for Description and Identification of Soils (Visual-Manual Procedures)
D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D4220/D4220M Practices for Preserving and Transporting Soil Samples
D4318 Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
D4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing
D5519 Test Methods for Particle Size Analysis of Natural and Man-Made Riprap Materials
D6026 Practice for Using Significant Digits in Geotechnical Data
D7928 Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis
E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves
E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Terminology

3.1 *General:*

3.1.1 An overview of terms used in the sieving processes is presented in Fig. 1(a) using a tabular format and in Fig. 1(b) using a flowchart format. In addition, Fig. 1(a) includes symbols used in the sieving processes.

3.1.2 There are two types of definitions in the following sections. There are definitions that are general (see 3.2) and others that are specific to this standard (see 3.3). To locate a definition, it may be necessary to review both sections. The definitions are in alphabetical order.

3.2 *Definitions:*

3.2.1 For definitions of general terms used in this test method, refer to Terminology D653.

3.2.2 *composite sieving, v—in sieving*, the process of separating a large specimen on a designated separating sieve to obtain coarser and finer particle-size portions. The coarser portion is sieved using the coarser sieve set. The finer portion is subsampled to obtain a subspecimen of manageable size (mass) and this subspecimen is sieved using the finer sieve set. The results of both sieve sets (coarser and finer) are combined mathematically to determine the gradation of the large specimen.

3.2.2.1 *Discussion*—In some cases the subspecimen may require another separation; that is, using a 2nd designated separating sieve and resulting in a 2nd coarser portion and 2nd subspecimen obtained from the 2nd finer portion.

3.2.3 *cumulative material retained (cumulative retained material or cumulative mass retained), n—in sieving*, the mass of material retained on an individual sieve plus the masses of material retained on all the coarser sieves in a given stack/set of sieves.

3.2.4 *cumulative percent retained, n—in sieving*, the ratio of cumulative material retained on a given sieve to the mass of the specimen, expressed in percent.

3.2.5 *designated separating sieve, n—in composite sieving*, the sieve selected to separate the specimen into coarser and finer portions for composite sieving.

3.2.5.1 *Discussion*—The designated separating sieve size is a standard sieve size typically ranging from the ¾-in. (19.0-mm) sieve to the No. 10 (2.00-mm) sieve. There can be two designated separating sieves used in composite sieving, that is the 1st subspecimen can be separated on a 2nd designated separating sieve to obtain a 2nd coarser portion and a 2nd subspecimen obtained from the 2nd finer portion.

3.2.6 *fractional cumulative material retained, n—in composite sieving*, when sieving a subspecimen, the mass of material retained on an individual sieve plus the masses of material retained on all the coarser sieves in a given sieve set.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

Terms [A]	Modifying Adjectives & Symbols
A – Single Sieve-Set Sieving	
specimen	moist (S,M_m), dry or oven-dried (S,M_d), air-dried (S,M_{ad}), washed (S_wM_d)
sieve set	
cumulative material or mass retained on *Nth* sieve	CMR_N
cumulative percent retained on *Nth* sieve	CPR_N
percent passing the *Nth* sieve [B]	PP_N
percent retained on *Nth* sieve [C]	PR_N
B – Composite Sieving: Single Separation, Only One Designated Separating Sieve Used	
specimen	Same as above.
designated separating sieve	
coarser portion	moist (CP,M_m), dry or oven-dried (CP,M_d), air-dried (CP,M_{ad}), washed ($CPwM_d$)
coarser sieve set	
cumulative material or mass retained on *Nth* sieve	CP,CMR_N
cumulative percent retained on *Nth* sieve	CP,CPR_N
percent passing the *Nth* sieve [B]	CP,PP_N
composite sieving correction factor	$CSCF$
finer portion	moist (FP,M_m), dry (FP,M_m), air-dried (FP,M_{ad})
subspecimen	moist ($SubS,M_m$), dry or oven-dried ($SubS,M_d$), air-dried ($SubS,M_{ad}$), washed ($SubS_w,M_d$)
finer sieve set	
fractional cumulative mass retained on *Nth* sieve	$SubS,FCMR_N$
fractional cumulative percent retained on *Nth* sieve	$SubS,FCPR_N$
fractional percent passing the *Nth* sieve	$SubS,FPP_N$
fractional percent retained the first sieve	$SubS,FPR_{first}$
finer portion percent passing the *Nth* sieve	FP,PP_N
percent passing the *Nth* sieve [D]	$SubS,PP_N$
C – Composite Sieving: Double Separation, 1st & 2nd Designated Separating Sieves Used	
specimen	Same as above.
1st designated separating sieve	
1st coarser portion	Same as above.
Same as above, except the prefix 1st is added to all terms	$1^{st}CP,CMR_N$, $1^{st}CP,CPR_N$, $1^{st}CP,PP_N$, $1^{st}CP,PP_N$, $1^{st}CSCF$
1st finer portion	Same as above.
1st subspecimen (used to produce 2nd subspecimen and 2nd coarser portion for sieving)	moist ($1^{st}SubS,M_m$), dry ($1^{st}SubS,M_d$), air-dried ($1^{st}SubS,M_{ad}$)
2nd designated separating sieve	
2nd coarser portion	dry or oven-dried ($2^{nd}CP,M_d$), washed ($2^{nd}CP_w,M_d$)
2nd finer portion	dry or oven-dried ($2^{nd}FP,M_d$)
2nd coarser sieve set	
1st fractional cum. mass retained on *Nth* sieve	$2^{nd}CP,FCMR_N$
1st fractional cum. percent retained on *Nth* sieve	$2^{nd}CP,,FCPR_N$
1st fractional percent passing the *Nth* sieve	$2^{nd}CP,FPP_N$
1st fractional percent retained on first sieve	$2^{nd}CP,FPR_{first}$
percent passing the *Nth* sieve [C]	$2^{nd}CP,PP_N$
finer portion percent passing the *Nth* sieve	FP,PP_N
2nd composite sieving correction factor	$2^{nd}CSCF$
1st finer portion composite sieving correction factor	$1^{st}FP, CSCF$
2nd subspecimen (selected from 2nd finer portion)	moist ($2^{nd}SubS,M_m$), dry ($2^{nd}SubS,M_d$), air-dried ($2^{nd}SubS,M_{ad}$)
finer sieve set	
2nd fractional cum. mass retained on *Nth* sieve	$2^{nd}SubS,FCMR_N$
2nd fractional cum. percent retained on *Nth* sieve	$2^{nd}SubS,FCPR_N$
2nd fractional percent passing the *Nth* sieve	$2^{nd}SubS,FPP_N$
2nd fractional percent retained on the first sieve	$2^{nd}SubS,FPR_{first}$
1st finer portion percent passing the *Nth* sieve	$1^{st}FP,PP_N$
percent passing the *Nth* sieve [D]	$2^{nd}SubS,PP_N$

Notes: [A] The term mass is omitted, since all non-percent terms are in mass (g). Some terms, such as material retained, percent retained (except as required) and fractional material are omitted since only the "cumulative" methodology is presented herein.

[B] Equals 100 minus cumulative percent retained. [C] Only required in precision determination.

[D] Function of the appropriate fractional percent passing and *CSCF*.

FIG. 1 (a) Typical Terminology and Symbols Used in Sieving Processes

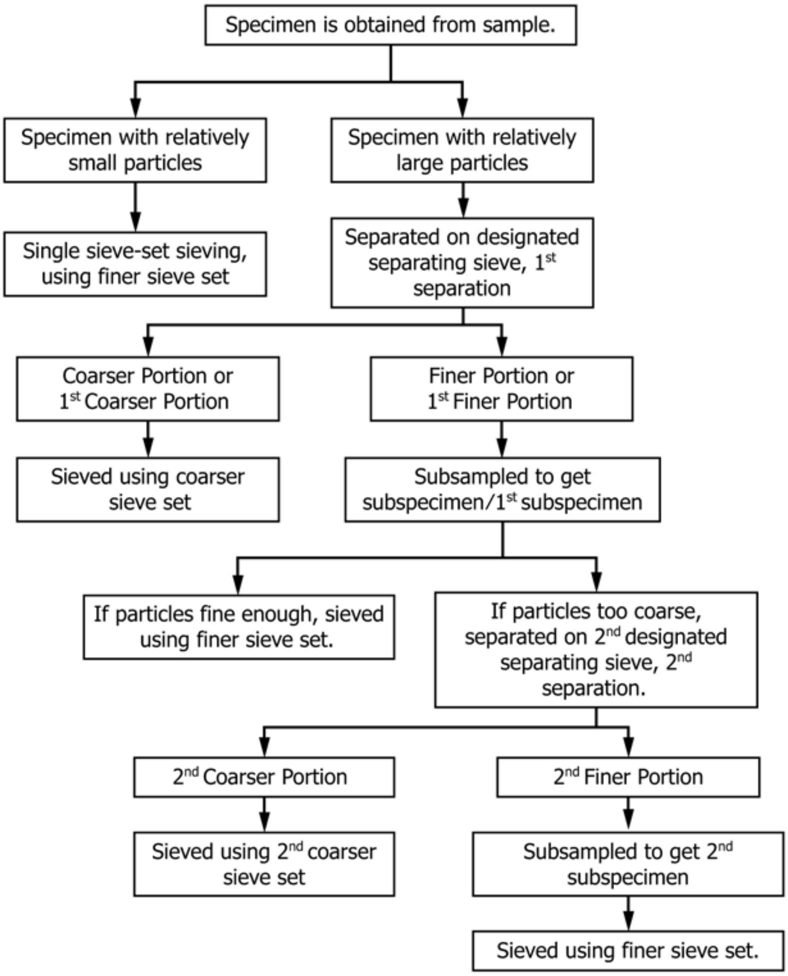


FIG. 1 (b) Terminology Flowchart for Sieving Processes *(continued)*

3.2.7 *fractional cumulative percent retained, n—in composite sieving*, the ratio of fractional cumulative material retained on a given sieve to the mass of the subspecimen, expressed in percent.

3.2.8 *fractional material retained, n—in composite sieving*, when sieving a subspecimen, the mass of material retained on an individual sieve.

3.2.9 *fractional percent passing, n—in composite sieving*, the portion of material by mass in the subspecimen(s) passing a given sieve expressed in percent.

3.2.9.1 *Discussion*—When two subspecimens are used, there will be a 1^{st} and 2^{nd} fractional percent passing.

3.2.10 *fractional percent retained, n—in composite sieving*, the ratio of fractional material retained on a given sieve to the mass of the subspecimen, expressed in percent.

3.2.11 *gradation, n—in soil*, the proportion by mass of various particle sizes.

3.2.11.1 *Discussion*—This proportion is usually presented in tabular format (sieve size and percent passing) or graphical format (percent passing versus logarithm of the sieve size in mm). The graphical format is referred to as particle-size distribution or gradation curve.

3.2.12 *maximum particle size, n—in sieving*, the smallest sieve size from the standard sieve set on which less than one percent of the sample would be retained.

3.2.12.1 *Discussion*—For practical purposes, estimate the maximum particle size as equal to the smallest sieve size from the standard sieve set in which it appears that all the material being tested would pass through that sieve. The maximum particle size is needed to determine the required mass of the specimen and subspecimen.

3.2.13 *maximum sieve size, n—in sieving*, the smallest sieve size that is larger than any particle in the specimen or subspecimen.

3.2.14 *minimum sieve size, n—in sieving*, the smallest sieve size in a sieve set used in sieving the specimen or subspecimen.

3.2.14.1 *Discussion*—This size is either the size of the designated separating sieve (1^{st} or 2^{nd}) or the No. 200 (75-µm) sieve.

3.2.15 *percent passing, n—in sieving*, the portion of material by mass in the specimen passing a given sieve expressed in percent.

3.2.15.1 *Discussion*—This value is equal to the cumulative material retained in a given sieve set divided by the mass of the specimen, subtracting that ratio from one, and then multiplying by 100. For composite sieving, it would be the fractional percent passing multiplied by the composite sieving correction factor (*CSCF*).

3.2.16 *particle size distribution, n*—see *gradation*.

3.2.17 *percent retained, n—in sieving*, the ratio of the material retained on a given sieve to the mass of the specimen, expressed in percent.

3.2.18 *saturated surface-dry condition, n—in coarse-grained soils*, a state in which the soil particles are basically saturated with water, but there are not visible films of water.

3.2.19 *sieve set, n—in sieving*, a set of standard sized sieves. For single sieve-set sieving, the sieve set will range from the maximum sieve size to the No. 200 (75-µm) sieve. For composite sieving, there will be a coarser sieve set and a finer sieve set. Together, these sets will range from the maximum sieve size to the No. 200 (75-µm) sieve. The designated separating sieve will be used as the minimum size in the coarser set and the maximum size in the finer set.

3.2.20 *sieve size, n—in sieving*, the size of the opening in the wire cloth of a given sieve in mm or µm.

3.2.21 *single sieve-set sieving, v—in sieving*, the process in which only one set of sieves is needed to determine the gradation of the specimen from the maximum particle size to the No. 200 (75-µm) sieve.

3.2.21.1 *Discussion*—Typically, this applies to specimens having a maximum particle size of 9.5 mm (⅜ in.) or less when using Method A or a maximum particle size of 4.75 mm (No. 4 sieve) or less when using Method B and the distribution of particles less than the No. 200 (75-µm) sieve is not needed.

3.2.22 *splitting, v—in sampling or subsampling*, the process of stockpile sampling, quartering material, or passing material through a splitter or riffle box to obtain a representative portion of that material for testing; that is, a specimen or subspecimen.

3.2.22.1 *Discussion*—A description of stockpile sampling, and quartering and splitting material is given in Annex A2, A2.1.1 through A2.1.3.

3.2.23 *standard shaking period, n—in sieving*, a time period ranging from 10 to 20 minutes that a mechanical sieve shaker operates during the sieving process and which has been verified to satisfy the requirements for sieving thoroughness.

3.2.24 *standard sieve set, n—in sieving soils*, the group of fourteen specific sieve sizes required to determine the gradation of soils between and including the 3-in. (75-mm) and No. 200 (75-µm) sieves, as listed in Table 1.

3.2.24.1 *Discussion*—Most of these sieve sizes are different than those used in aggregate testing for concrete (Test Method C136), especially for sieves finer than the No. 4 (4.75 mm).

3.2.25 *subspecimen, n—in composite sieving*, a representative portion of the material passing the designated separating sieve; that is, the finer portion.

3.2.25.1 *Discussion*—When composite sieving requires multiple designated separating sieves, there will be more than one subspecimen. The 1st subspecimen (that is, the subspecimen from the finer portion) would be separated into a 2nd coarser portion and a 2nd finer portion that would be subsampled to obtain the 2nd subspecimen.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *coarser portion, n—in composite sieving*, the portion of the specimen retained on the designated separating sieve.

3.3.1.1 *Discussion*—When two designated separating sieves are used, there will be a 1st and 2nd coarser portion.

3.3.2 *coarser sieve set, n—in composite sieving*, the sieve set that ranges from the maximum sieve size to the designated separating sieve size.

3.3.2.1 *Discussion*—When two designated separating sieves are used, the 1st coarser sieve set ranges from the maximum sieve size to the 1st designated separating sieve size. The 2nd coarser sieve set would range from the 1st designated separating sieve size to the 2nd designated separating sieve size.

3.3.3 *composite sieving correction factor (CSCF), n—in composite sieving*, a factor used to convert the fractional percent passing determined from sieving the subspecimen to the percent passing for the specimen. The *CSCF* is equal to the percent passing the designated separating sieve size in the coarser portion sieve set (that is, the last sieve in the coarser portion set). This value shall be calculated to one more digit than required (0.1 %) to reduce rounding errors.

3.3.3.1 *Discussion*—When two designated separating sieves are used, there will be a 1st and 2nd*CSCF*.

3.3.4 *finer portion, n—in composite sieving*, the portion of the specimen passing the designated separating sieve.

3.3.4.1 *Discussion*—When two designated separating sieves are used, the 1st subspecimen obtained from the 1st finer portion will be separated into a 2nd coarser portion and 2nd finer portion, from which the 2nd subspecimen is obtained.

TABLE 1 Standard Sieve Set[A]

Sieve Designation in Accordance with E11			
Alternative	Standard	Alternative	Standard
Lid		No. 10	2.00 mm
3 in.	75 mm	No. 20	850 µm
2 in.	50 mm	No. 40	425 µm
1-½ in.	37.5 mm	No. 60	250 µm
1 in.	25.0 mm	No. 100	150 µm
¾ in.	19.0 mm	No. 140	106 µm
⅜ in.	9.5 mm	No. 200	75 µm
No. 4	4.75 mm	Pan	

[A] A lid is typically not used or needed when using rectangular coarser sieves having dimensions greater than 200 mm or 8 in.

3.3.5 *finer sieve set, n—in composite sieving*, the sieve set that ranges from the last designated separating sieve size to the No. 200 (75-µm) sieve.

3.3.5.1 *Discussion*—When composite sieving requires a 2nd subspecimen, the finer sieve sets ranges from the 2nd separating sieve size to the No. 200 (75-µm) sieve.

3.3.6 *insignificant sieve, n—in precision of test results*, any sieve which has 1 % or less cumulative material retained during the sieve analysis.

3.3.7 *separating, v—in composite sieving*, the process of dividing a specimen or subspecimen into two portions, the coarser (retained) and finer (passing) portions, using a designated separating sieve.

3.3.7.1 *Discussion*—When composite sieving requires two designated sieves, there will be a 1st and 2nd coarser portion, finer portion and subspecimen.

3.3.8 *significant sieve, n—in precision of test results*, any sieve which has more than 1 % of cumulative material retained during the sieve analysis.

4. Summary of Test Method

4.1 This test method is used to determine the particle-size distribution (gradation) of a soil sample. A representative specimen must be obtained from the sample by one of three procedures (moist, air-dried or oven-dried). For specimens containing relatively small particles, the specimen is sieved in its entirety, using single sieve-set sieving. However, the specimen may contain a wide range of particle sizes and may require separating the soil into two, or three size ranges for more efficient sieving, using one or two designated separating sieve(s). This process is termed composite sieving. For a single separation (two portions), the coarser portion is sieved in its entirety, while the finer portion is split into a smaller subspecimen for sieving. These results are mathematically combined. For specimens containing very large particles, the specimen may require two separations; that is, three portions (1st and 2nd coarser portions and 2nd finer portion), see Fig. 1(a) and Fig. 1(b). Prior to sieving, as applicable, the material will be washed to remove fine particles and oven dried. The material to be sieved will be placed on the coarsest sieve size of each sieve set and mechanically shaken. The mass of particles retained on each sieve will be determined. The results will produce a tabulation of sieve sizes versus percent passing that can be graphically presented as a gradation curve (a plot of the percent passing versus the log of the particle size in mm.).

4.2 Flowcharts outlining the requirements of the various sieving processes covered above are presented below in four figures, Fig. 2 through Fig. 4(b).

5. Significance and Use

5.1 The gradation of the soil is used for classification in accordance with Practice D2487.

5.2 The gradation (particle-size distribution) curve is used to calculate the coefficient of uniformity and the coefficient of curvature.

5.3 Selection and acceptance of fill materials are often based on gradation. For example, highway embankments, backfills, and earthen dams may have gradation requirements.

5.4 The gradation of the soil often controls the design and quality control of drainage filters, and groundwater drainage.

5.5 Selection of options for dynamic compaction and grouting is related to gradation of the soil.

5.6 The gradation of a soil is an indicator of engineering properties. Hydraulic conductivity, compressibility, and shear strength are related to the gradation of the soil. However, engineering behavior is dependent upon many factors (such as effective stress, stress history, mineral type, structure, plasticity, and geologic origins) and cannot be based solely upon gradation.

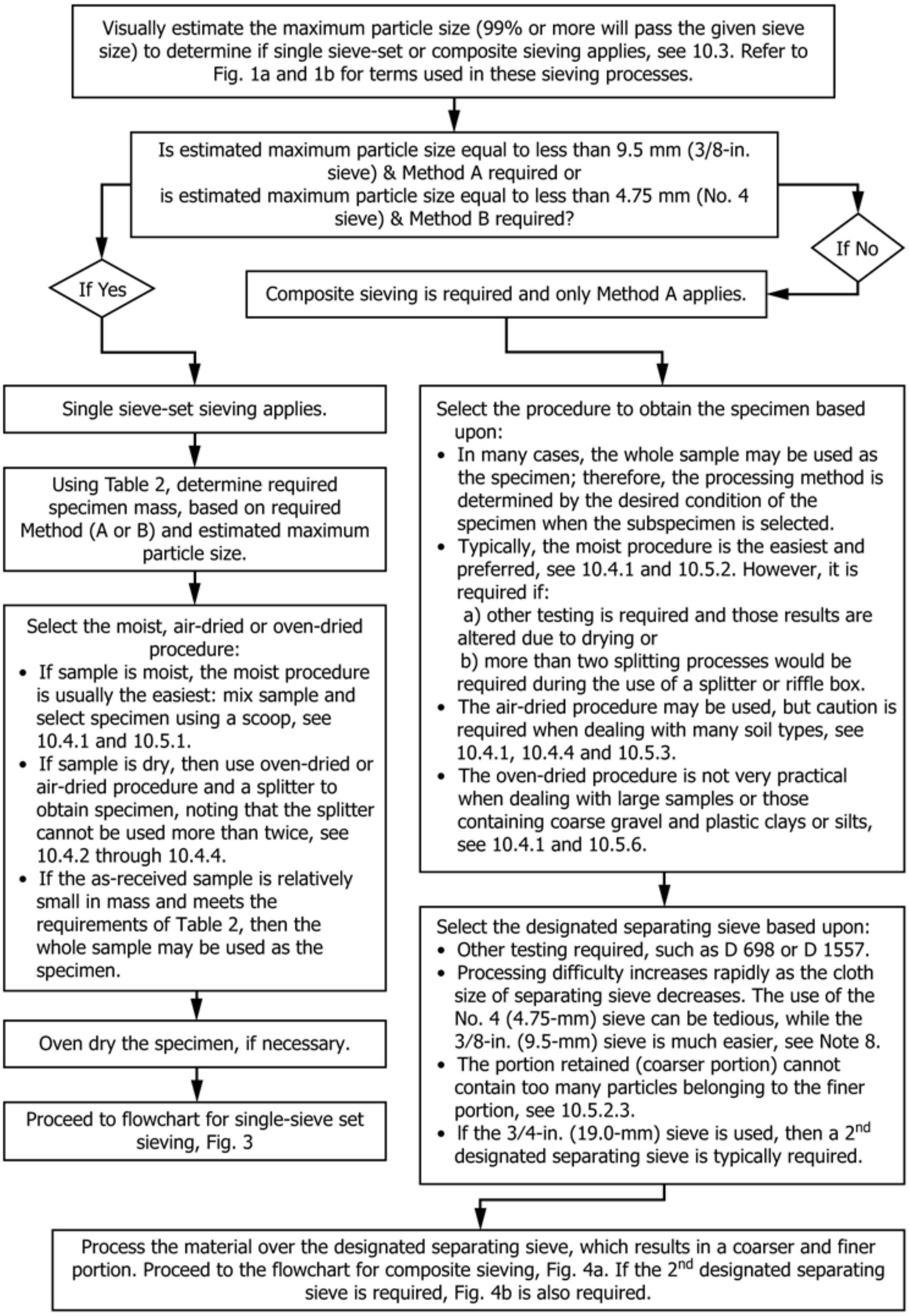
NOTE 1—The quality of the result produced by these test methods is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of these test methods are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *Sieves*—Each sieve shall conform to the requirements of Specification E11. Generally, these sieve frames are circular and 200 mm or 8 in. in diameter, and either full (50 mm or 2 in.) or half height (25 mm or 1 in.). The sieve height generally depends upon the number of sieves typically required in the sieve set, the particle sizes being sieved, and the size and type of the sieve shaker. Particles having dimensions exceeding or relatively close to the sieve heights cannot be sieved in the sieve stack, but individually. Therefore, in a stack of sieves, the ratio of sieve height or spacing between rectangular sieves to sieve cloth opening shall exceed 2. Larger frames that conform to Specification E11 are acceptable but require special considerations for reinforcement.

6.1.1 *Standard Sieve Set*—This set consists of all the sieve sizes listed in Table 1. Additional sieves sizes may be added if requested or needed to reduce sieve overloading. In addition, some larger sieve sizes may be omitted during the sieve analysis depending on the maximum particle size; however, at least one sieve in the sieving process shall have 100 percent passing.

6.1.2 *Washing Sieve, No. 200 (75-µm)*—A No. 200 (75-µm) sieve with a minimum height above the screen of 50 mm or 2 in. to prevent loss of retained material while washing. Stainless steel sieve cloth is preferred because it is more durable, and less prone to damage or wear. The sieve may be reinforced with a larger mesh underneath the 75-µm cloth. The reinforcement wire cloth (backing) should not have a mesh coarser than the No. 20 (850-µm) wire cloth. The reinforcement wire cloth should be bonded to the sieve frame along with the No. 200 (75-µm) wire cloth, not bonded to the sieve frame below where the No. 200 (75-µm) wire cloth was attached. In addition, it is good practice to use a flattened backing cloth (rolled or calendered backing cloth), so it is less abrasive to the No. 200 (75-µm) wire cloth.



Visually estimate the maximum particle size (99% or more will pass the given sieve size) to determine if single sieve-set or composite sieving applies, see 10.3. Refer to Fig. 1a and 1b for terms used in these sieving processes.

Is estimated maximum particle size equal to less than 9.5 mm (3/8-in. sieve) & Method A required or is estimated maximum particle size equal to less than 4.75 mm (No. 4 sieve) & Method B required?

Composite sieving is required and only Method A applies.

Single sieve-set sieving applies.

Using Table 2, determine required specimen mass, based on required Method (A or B) and estimated maximum particle size.

Select the moist, air-dried or oven-dried procedure:

- If sample is moist, the moist procedure is usually the easiest: mix sample and select specimen using a scoop, see 10.4.1 and 10.5.1.
- If sample is dry, then use oven-dried or air-dried procedure and a splitter to obtain specimen, noting that the splitter cannot be used more than twice, see 10.4.2 through 10.4.4.
- If the as-received sample is relatively small in mass and meets the requirements of Table 2, then the whole sample may be used as the specimen.

Oven dry the specimen, if necessary.

Proceed to flowchart for single-sieve set sieving, Fig. 3

Select the procedure to obtain the specimen based upon:

- In many cases, the whole sample may be used as the specimen; therefore, the processing method is determined by the desired condition of the specimen when the subspecimen is selected.
- Typically, the moist procedure is the easiest and preferred, see 10.4.1 and 10.5.2. However, it is required if:
  a) other testing is required and those results are altered due to drying or
  b) more than two splitting processes would be required during the use of a splitter or riffle box.
- The air-dried procedure may be used, but caution is required when dealing with many soil types, see 10.4.1, 10.4.4 and 10.5.3.
- The oven-dried procedure is not very practical when dealing with large samples or those containing coarse gravel and plastic clays or silts, see 10.4.1 and 10.5.6.

Select the designated separating sieve based upon:

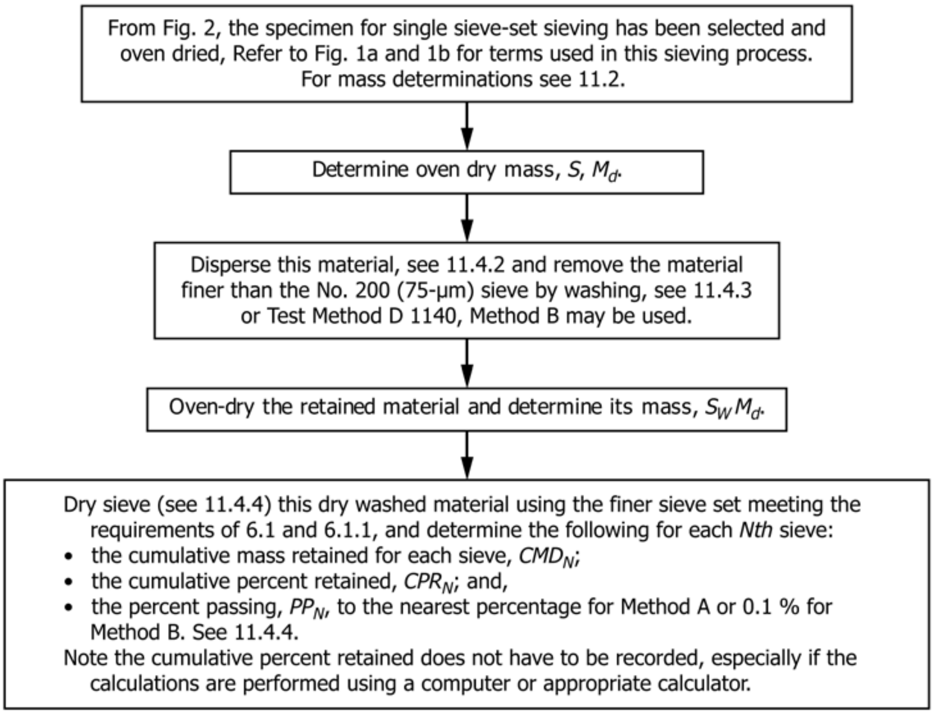
- Other testing required, such as D 698 or D 1557.
- Processing difficulty increases rapidly as the cloth size of separating sieve decreases. The use of the No. 4 (4.75-mm) sieve can be tedious, while the 3/8-in. (9.5-mm) sieve is much easier, see Note 8.
- The portion retained (coarser portion) cannot contain too many particles belonging to the finer portion, see 10.5.2.3.
- If the 3/4-in. (19.0-mm) sieve is used, then a 2nd designated separating sieve is typically required.

Process the material over the designated separating sieve, which results in a coarser and finer portion. Proceed to the flowchart for composite sieving, Fig. 4a. If the 2nd designated separating sieve is required, Fig. 4b is also required.

FIG. 2 Decision Flowchart for Sieving Processes

6.1.3 *Designated Separating Sieve*—A sieve used to separate the specimen into two portions (coarser and finer portion) in composite sieving. The designated separating sieve shall conform to Specification E11. It may be necessary to have various sizes of sieves to use as designated separating sieves. Normally, these are not the same sieves that are used in the stack of sieves (sieve set) placed in the sieve shaker. Typically, the 1st designated separating sieve is rectangular and quite large, while the 2nd designated separating sieve is either 200-mm or 8-in. in diameter.

6.2 *Washing Sink with Spray Nozzle*—A sink having a spray nozzle attached to a flexible line to facilitate the washing and material transferring processes without spillage. In addition, the spray nozzle shall be such that the rate of water flow can be easily controlled. The temperature of the water shall be



From Fig. 2, the specimen for single sieve-set sieving has been selected and oven dried, Refer to Fig. 1a and 1b for terms used in this sieving process. For mass determinations see 11.2.

Determine oven dry mass, S, M_d.

Disperse this material, see 11.4.2 and remove the material finer than the No. 200 (75-µm) sieve by washing, see 11.4.3 or Test Method D 1140, Method B may be used.

Oven-dry the retained material and determine its mass, $S_W M_d$.

Dry sieve (see 11.4.4) this dry washed material using the finer sieve set meeting the requirements of 6.1 and 6.1.1, and determine the following for each *Nth* sieve:

- the cumulative mass retained for each sieve, CMD_N;
- the cumulative percent retained, CPR_N; and,
- the percent passing, PP_N, to the nearest percentage for Method A or 0.1 % for Method B. See 11.4.4.

Note the cumulative percent retained does not have to be recorded, especially if the calculations are performed using a computer or appropriate calculator.

FIG. 3 Flowchart for Single Sieve-Set Sieving

relatively close to room temperature to prevent changing the dimensions of the sieve cloth and health and safety concerns.

6.3 *Mechanical Sieve Shaker*—A device that holds a stack of sieves while imparting sufficient motion to the sieves to meet the sieving thoroughness requirements covered in 8.2. The "Standard Shaking Period" must be from 10 to 20 minutes. The shaker shall have a timing device or a timing device shall be used in conjunction with the shaker.

NOTE 2—Shakers imparting a motion that causes the particles on the sieves to bounce and turn so that all particles have ample opportunity in various orientations to the sieve openings will typically meet this sieving thoroughness requirement. A sieve shaker that has a smooth horizontal and/or vertical gyratory/orbital motion will typically ***not*** meet this sieving thoroughness requirement, since the particles will not be bouncing and turning.

6.4 *Balances*—For single sieve-set sieving, one balance will be used. For composite sieving, more than one balance may be necessary. Balances must conform to the requirements of Specification D4753; that is, having a readability (with no estimation) to determine the mass of the specimen or subspecimen to a minimum of three significant digits for Method A or a minimum four significant digits for Method B. The mass of the specimen can be determined in parts (multiple mass determinations). The balance used to determine the cumulative material retained or the fractional cumulative material retained on any given sieve has to have a readability equal to or better than that used to determine the mass of the specimen/subspecimen.

NOTE 3—Preferably the balance should have a taring capability so that the mass of material can be directly determined without subtracting the mass of the container. This feature is immensely useful during the sieving process to determine the mass of the cumulative material retained or when making multiple mass determinations to determine specimen's mass.

6.5 *Drying Oven*—Thermostatically controlled oven, capable of maintaining a uniform temperature of 110 ± 5°C throughout the drying chamber. These requirements typically require the use of a forced-draft oven.

6.6 *Sieving Containers*—The containers used to: *(a)* contain the sieving specimen or material which will be sieved, such as coarser portion; *(b)* remove the retained material from the sieve(s); *(c)* collect and transfer that material; and, *(d)* contain the cumulative material retained.

6.6.1 *Specimen Containers*—Smooth walled containers, without tight corners to trap material, made of material resistant to corrosion and change in mass upon repeated heating, cooling, specimen soaking, and cleaning. The containers should be large enough to enable soaking of the specimen. The container should facilitate the transfer of the specimen from the container to the washing sieve (No. 200 (75 µm) or designated separating sieve) and back by a rinsing/washing operation, and allow for decanting the clear wash water from the container.

6.6.2 *Collection/Transfer Container*—This container is used to collect the material retained on a given sieve and to transfer it to the container holding the cumulative retained material during the sieving process. The container must be larger in diameter than the sieve. A smoothsurface 230-mm (9-in.) pie pan may be used along with a 25-mm (1-in.) paintbrush to assist in transferring all the material. The color of this container shall enhance the observation that all material has been transferred.

6.6.3 *Cumulative Mass Container*—This container shall be large enough to receive the retained material contained in the collection/transfer device without any loss. The mass should be

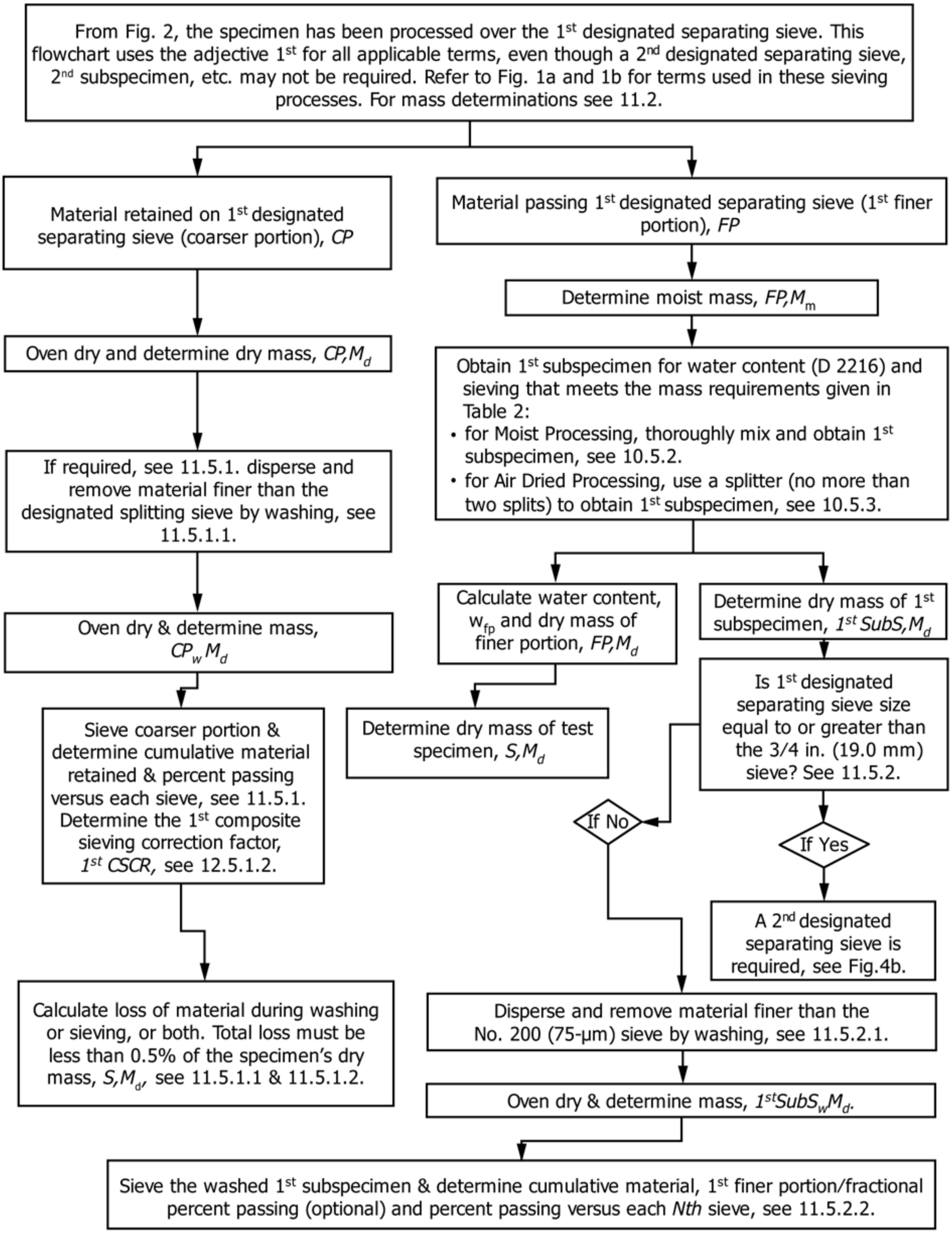
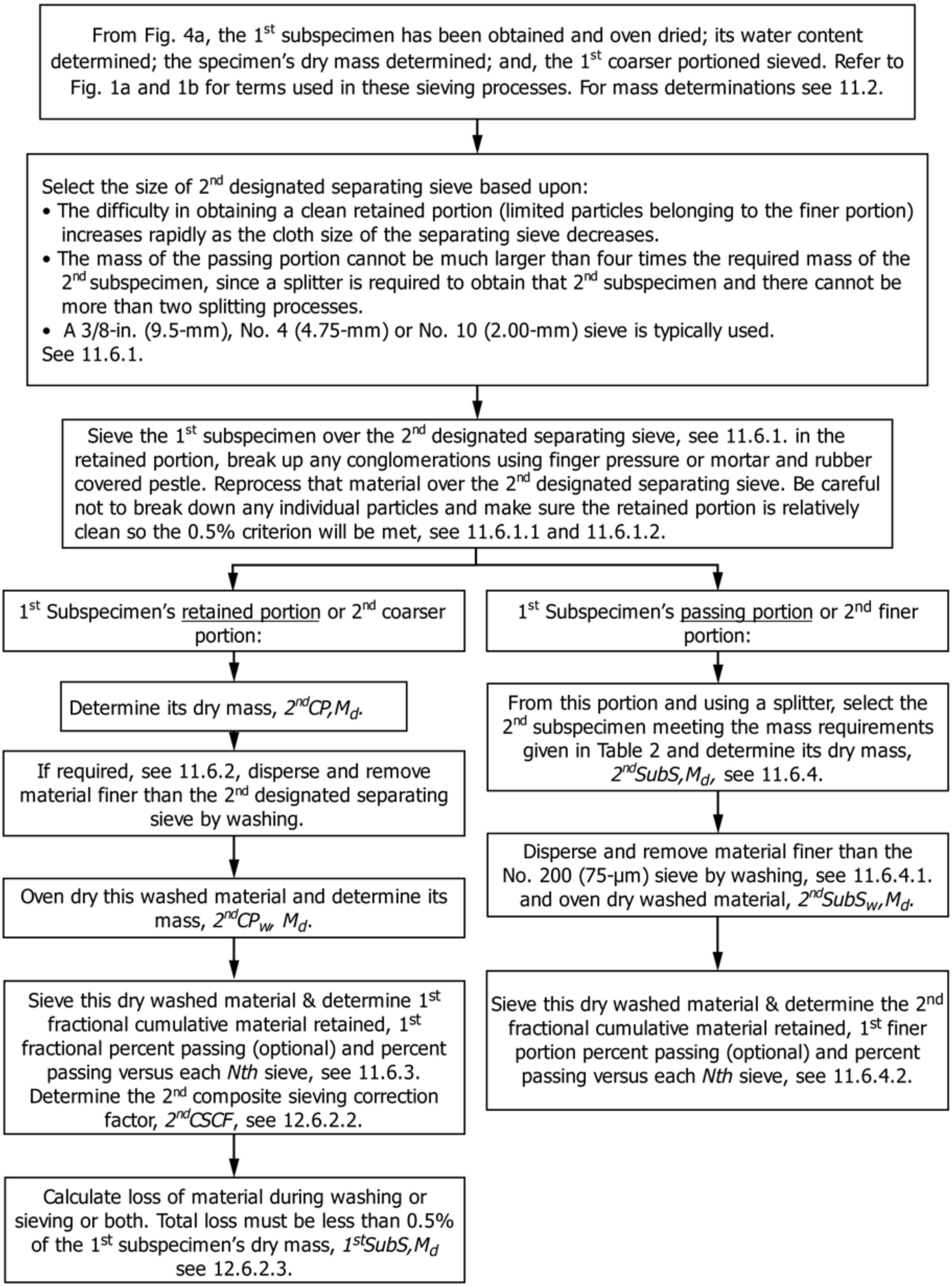


FIG. 4 (a) Flowchart for Composite Sieving—Single Separation



From Fig. 4a, the 1st subspecimen has been obtained and oven dried; its water content determined; the specimen's dry mass determined; and, the 1st coarser portioned sieved. Refer to Fig. 1a and 1b for terms used in these sieving processes. For mass determinations see 11.2.

Select the size of 2nd designated separating sieve based upon:

- The difficulty in obtaining a clean retained portion (limited particles belonging to the finer portion) increases rapidly as the cloth size of the separating sieve decreases.
- The mass of the passing portion cannot be much larger than four times the required mass of the 2nd subspecimen, since a splitter is required to obtain that 2nd subspecimen and there cannot be more than two splitting processes.
- A 3/8-in. (9.5-mm), No. 4 (4.75-mm) or No. 10 (2.00-mm) sieve is typically used.

See 11.6.1.

Sieve the 1st subspecimen over the 2nd designated separating sieve, see 11.6.1. in the retained portion, break up any conglomerations using finger pressure or mortar and rubber covered pestle. Reprocess that material over the 2nd designated separating sieve. Be careful not to break down any individual particles and make sure the retained portion is relatively clean so the 0.5% criterion will be met, see 11.6.1.1 and 11.6.1.2.

1st Subspecimen's <u>retained portion</u> or 2nd coarser portion:

Determine its dry mass, $2^{nd}CP, M_d$.

If required, see 11.6.2, disperse and remove material finer than the 2nd designated separating sieve by washing.

Oven dry this washed material and determine its mass, $2^{nd}CP_w, M_d$.

Sieve this dry washed material & determine 1st fractional cumulative material retained, 1st fractional percent passing (optional) and percent passing versus each *Nth* sieve, see 11.6.3. Determine the 2nd composite sieving correction factor, $2^{nd}CSCF$, see 12.6.2.2.

Calculate loss of material during washing or sieving or both. Total loss must be less than 0.5% of the 1st subspecimen's dry mass, $1^{st}SubS, M_d$ see 12.6.2.3.

1st Subspecimen's <u>passing portion</u> or 2nd finer portion:

From this portion and using a splitter, select the 2nd subspecimen meeting the mass requirements given in Table 2 and determine its dry mass, $2^{nd}SubS, M_d$, see 11.6.4.

Disperse and remove material finer than the No. 200 (75-µm) sieve by washing, see 11.6.4.1. and oven dry washed material, $2^{nd}SubS_w, M_d$.

Sieve this dry washed material & determine the 2nd fractional cumulative material retained, 1st finer portion percent passing (optional) and percent passing versus each *Nth* sieve, see 11.6.4.2.

FIG. 4 (b) Flowchart for Composite Sieving—Double Separation *(continued)* less than the taring capacity of the balance so that the cumulative mass retained can be determined directly (see Note 3). In most cases, the specimen/subspecimen container can be used. This test method assumes that the mass of the cumulative retained material is determined directly. This approach is easier than determining the mass of retained material on each sieve.

6.7 *Sieve Brushes*—Brushes to assist in the removal of the material retained on the smaller (≤200-mm or 8-in.) diameter and finer sieve sizes (≤¾-in. (19.0-mm)). The brushes shall have the following characteristics:

6.7.1 The bristles shall be firmly attached to the brush handle so that the bristles do not become part of the retained material.

6.7.2 The bristles shall be firm and small enough to readily remove the particles entangled in the sieve openings, but made of a material that will not damage the wire cloth or wear rapidly. Wire bristles, even brass, shall ***not*** be used on wire cloth size finer than No. 20 (850–µm).

6.7.3 The bristles shall be capable of contacting the boundary between the wire cloth and sieve's frame.

6.7.4 The brush's handle shall be such that one's hand can easily control the brushing motion and pressure. An example being, the handle is above the bristles (like a paintbrush) or inclined (30- to 45-degree angle) to the bristle's head (like a vegetable brush or bent toothbrush).

6.7.5 The bristles have to be small in diameter and soft when brushing wire cloth size equal to or less than the No. 100 (150-µm) mesh. Small diameter, soft bristles will remove the particles without any re-alignment of the wire cloth.

6.7.6 Brushes meeting these requirements are relatively small round or rectangular stiff paintbrushes with shortened bristles, soft to hard toothbrushes with bent handles, and vegetable brushes with shortened bristles.

6.8 *Miscellaneous Items*—Miscellaneous items such as wash bottle, spatula, and stirring rod may be useful.

6.9 *Splitter or Riffle Box (optional, but may be needed during composite sieving)*—A device to obtain a representative smaller portion (specimen) from a larger portion (sample). This device has an even number of equal width chutes, but not less than eight, which discharge alternately to each side of the splitter. For dry material having particles coarser than the ⅜-in. (9.5-mm) sieve size, the minimum width of the chutes shall be approximately 1-½ times the largest particle in material being split, but not less than 12.5 mm or ½ in. For dry material finer than or equal to the ⅜-in. (9.5-mm) sieve size, the minimum chute width shall be approximately 1-½ times the largest particle in the material, but not less than approximately 3 mm or ⅛ in. The splitter shall be equipped with two or more receptacles to hold the two halves of the material following splitting. It shall also be equipped with a hopper/feed chute (preferably lever activated or having a cut-off gate) and a straight-edged pan or dustpan that has a width equal to or slightly less than the over-all width of the assembly of chutes, by which the dry material may be fed at a controlled rate to the chutes. The splitter and accessory equipment shall be so designed that the material will flow smoothly without restriction or loss of material.

NOTE 4—Some splitters are designed such that the width of the chutes can be adjusted.

6.10 *Quartering Accessories (optional)*—A hard, clean, level surface, or durable nonporous fabric or plastic sheet approximately 2 by 2.5 m or 6 by 8 ft; a straight-edged scoop, shovel, or trowel; and a broom or brush.

6.11 *Mortar and Rubber-Covered Pestle (optional)*—Apparatus for breaking up aggregations of air-dried or oven-dried soil particles without breaking up any individual particles.

6.12 *Low Temperature Drying Oven (optional)*—Thermostatically controlled oven, capable of maintaining a uniform temperature not to exceed 60°C throughout the drying chamber, for use in air-dried processing.

6.13 *Ultrasonic Water Bath (optional)*—The ultrasonic water bath must be large enough to hold a beaker or flask containing the material to be dispersed prior to washing. The water level in the bath should be equal or higher than the water level in the specimen container.

6.14 *Dispersion Shaker (optional)*—A platform, wrist action or similar type shaker having a gyratory, orbital, reciprocating, or similar motion to assist in the dispersion process by continuously agitating the soaking soil.

7. Reagents

7.1 *Sodium Hexametaphosphate*—Also referred to as sodium metaphosphate, is the dispersion agent used to disperse some fine-grained soils after oven drying and prior to washing. Fine-grained soils requiring the use of a dispersant are those that do not readily slake in water, such as some fat clays and most tropical soils.

7.1.1 For materials needing a chemical dispersant, the dispersant can be added either directly to the soaking material (dry addition) or by adding a dispersant solution to the material, plus water as necessary.

7.1.1.1 *Dry Addition*—Add about 4 grams of sodium hexametaphosphate for each 100 mL of water that has been added to the soaking material and stir to distribute the dispersant throughout the material.

7.1.1.2 *Solution*—Make a solution by using 40 g of sodium hexametaphosphate and 1,000 g distilled, deionized, or demineralized water. Add the solution to the material, plus water if needed and stir to distribute the dispersant throughout the material. The solution must be less than one week old and thoroughly mixed or shaken prior to use. The date of preparation must be indicated on the bottle or in a log.

NOTE 5—Solutions of this salt, if acidic, slowly revert or hydrolyze back to the orthophosphate form with a resultant decrease in dispersive action.

8. Preparation of Apparatus

8.1 *Verification of Sieves*—Prior to ***initial use***, evaluate each sieve for general condition of the wire cloth as specified in Test Method One of Specification E11. That method provides the following evaluation instructions, "view the sieve cloth against a uniformly illuminated background. If apparent deviations, for example, weaving defects, creases, wrinkles, and foreign matter in the cloth, are found, the wire cloth (sieve) is unacceptable.” This evaluation shall be documented. Unacceptable sieves shall be replaced and discarded or returned to the manufacturer for repair (wire cloth).

8.1.1 *Verification Interval*—The same evaluation shall be performed and documented at 6-month intervals on all sieves that are placed in continuous service. However, for sieves that have a limited usage of less than about 1,000 sieve analyses per 6-month interval, then this interval may be increased to 12 months. Sieves that contain excessive soil particles (about 10 % of the sieve openings contain particles) shall be thoroughly cleaned. An ultrasonic water bath may be used to clean the finer sieve sizes, while a stiffer brush or pointed tool can be used to clean the coarser sieves.

8.1.2 During each sieving process, the sieves finer than and including the No. 100 (150-μm) sieve shall be checked for damaged cloth, such as tearing at the frame contact. This check can be done while the retained material is being removed from the sieve during the sieving process. This check does not need to be documented.

8.2 *Verification of Mechanical Sieve Shaker and Standard Shaking Period*—Prior to ***initial use***, the mechanical sieve shaker shall be checked for sieving thoroughness using applicable sieve sets (typically used coarser and finer) and representative material. In addition, the standard shaking period shall be determined for each applicable sieve set. For each size sieve set, follow the guidance given for single sieve-set sieving (see 11.4). Use enough material (specimen) of known mass (g or kg) such that each sieve in the set, except one or two, will have some retained material but no sieve will be overloaded. Shake the sieve set for ten minutes with the mechanical shaker. Upon completion of mechanical shaking, start with the largest sieve size and place the snug-fitting lid on top of the sieve and the pan underneath it. Shake each sieve by hand, for about one minute using the hand shaking procedure (see 8.2.3). For each sieve, determine the mass of material retained on the sieve and in the pan, to the nearest 0.01 g or one part in 1,000, whichever is largest. The ratio of the material mass in the pan to the specimen’s mass multiplied by 100 for each sieve shall be less than 0.5 % (see Note 6). If all ratios are less than 0.5 %, the sieve shaker with a 10-minute shaking period is adequate and shall be used as the standard shaking period for that sieve set. If any ratio is equal to or exceeds 0.5 %, repeat the process using a 15-minute shaking period. If this shaking period meets the above criterion, then it shall be used as the standard shaking period for that sieve set, unless a shorted shaking period, like 12 minutes is verified as adequate. If the 15-minute shaking period fails, then try the maximum allowable shaking period of 20 minutes. If the 20-minute shaking period fails, then the mechanical sieve shaker shall be considered inadequate for sieving. It shall either be repaired or discarded. After repair, repeat the instructions given above to determine the standard shaking period.

8.2.1 *Large Mechanical Sieve Shaker*—If a larger mechanical sieve shaker is used to shake large diameter (greater than 200 mm or 8 in.) or rectangular sieve sets and hand shaking is not practicable, then transfer the retained material in appropriate increments to a 200- mm or 8-in. diameter sieve of equal sieve designation, with lid and pan, and shake for one minute. Follow the instructions given above to determine the standard shaking period for each sieve set.

8.2.2 *Verification Interval*—The same verification shall be performed and documented at 12-month intervals for each sieve shaker placed in continuous service. However, for sieve shakers that have a limited usage of less than about 1,000 sieve analyses per 12-month interval, then this interval may be increased to 24 months. Not all sieve set sizes (coarser and finer) have to be re-verified unless the standard shaking time changes for the sieve set being verified. The finer sieve set or the set having the longest standard shaking period shall be used for re-verification.

NOTE 6—For example, after hand shaking the No. 4 (4.75 mm) sieve, the amount of material retained in the pan is 0.20 g. If the specimen mass is 100.00 g, then the ratio is 0.2% = ((0.20/100.00)*100). In this example, if the amount in the pan had been greater than 0.50 g, the ratio would exceed 0.5 % and the verification process would be repeated with a longer time interval.

8.2.3 *Hand Sieve Shaking Procedure*—For 200-mm or 8-in. diameter sieves, hold the individual sieve, with lid and pan, in a slightly inclined (about 15°) position in one hand. Strike the side of the sieve sharply with the heel of the other hand using an upward motion and at a rate of about 150 times per minute, turn the sieve about one sixth of a revolution at intervals of about 25 strokes. Continue for about one minute.

8.2.3.1 For larger diameter or rectangular sieves, transfer the retained material to 200-mm or 8-in. diameter sieves, in appropriate portions to prevent overloading (see 11.3), and follow the above instructions for each portion.

9. Sampling

9.1 *General*—This test method does not cover, in any detail, procurement of the sample. It is assumed that the sample is obtained using appropriate methods and is representative. However, the testing agency shall preserve all samples in accordance with Practice D4220/D4220M, Group B; except if the as-received sample does not meet those requirements. In that case, the water content of the material does not have to be maintained. The mass of the sample shall meet or exceed the mass requirements for the specimen, as given in Table 2 (see 10.2).

9.2 *Sample Sources*—The sample for a sieve analysis can be from a variety of sources and contain a wide range of particle sizes. Typically, samples for sieve analysis are obtained in the following forms: bulk samples (large bag or bucket samples), small bag or jar samples, tube samples, or specimens from other tests (such as strength, consolidation or hydraulic conductivity). In some cases, (for example, compaction testing) prior testing may cause a reduction of particle sizes. For these cases, the sieve analysis may be required on the initial specimen, or the degraded specimen or both. An overview of how specimens may be selected for various sample types is given below; whereas details for obtaining specimens from samples are in Section 10.

9.2.1 *Bulk Samples*—Generally, bulk samples are obtained because multiple tests are needed or large particles are present, or both. In addition, the bulk sample will usually become the

TABLE 2 Minimum Mass Requirement for Specimen

Maximum Particle Size of Material (99 % or more passes)		Minimum Dry Mass of Specimen, g or kg[A]	
Alternative Sieve Designation	Maximum Particle Size, mm	Method A Results Reported to Nearest 1 %	Method B Results Reported to Nearest 0.1 %
No. 40	0.425	50 g	75 g
No. 10	2.00	50 g	100 g
No. 4	4.75	75 g	200 g[B]
⅜ in.	9.5	165 g[C]	[D]
¾ in.	19.0	1.3 kg[C]	[D]
1 in.	25.4	3 kg[C]	[D]
1-½ in.	38.1	10 kg[C]	[D]
2 in.	50.8	25 kg[C]	[D]
3 in.	76.2	70 kg[E]	[D]

[A] Specimen masses should not significantly exceed (by more than about 50 %) the presented values because excessively large specimens may result in sieve overloading, (see 11.3) and increase the difficulty of specimen processing.

[B] The same as "C," except multiplied by 10.

[C] These values are based on the mass of an individual spherical shaped particle, at the given sieve, multiplied by 100 then 1.2 (factor to account uncertainty) and finally rounded to a convenient number.

[D] Specimens of this size require composite sieving. The sample sizes required for reporting results to 0.1 % are not practical and the possible errors associated with composite sieving causes this sensitivity to be unrealistic for specimens with these larger size particles.

[E] Same as "C," except 1.2 factor is omitted.

specimen and composite sieving will be required. If other testing is needed, these tests should be coordinated with the sieve analysis so that all specimens are obtained efficiently and representatively using moist (preferred) or air-dried procedure. For example, Test Method D698 or D1557 is frequently requested on bulk samples in addition to the sieve analysis. For this test, it is probably most efficient to process the as-received sample, now a specimen, over the designated separating sieve having either the ¾-in. (19.0-mm), ⅜-in. (9.5-mm) or No. 4 (4.75- mm) sieve and obtain the sieve specimens (coarser and finer portions) during this processing. Although oversize particles (coarser portion) are not used in testing with D698 or D1557, the composite sieve analysis should be calculated to represent both the bulk sample and the compaction material (two gradations). Flowcharts presenting an overview of this procedure are presented in Fig. 2 through Fig. 4(b).

9.2.2 *Jar and Small Bag Samples*—Depending on the sample's gradation, it may be necessary to use the entire sample for the specimen. Observe and estimate the maximum particle size. If the amount of material in the sample is less than the minimum mass required (as given in Table 2), note that the specimen is undersized. If the amount (by mass) of sample is much more (by about 50 %) than needed, the sample can be reduced using moist (preferred) or oven-dried procedure. If there is other testing to be obtained from the sample, it may be better to perform the other testing, such as water content and specific gravity and then sieve the used material. Note on the data sheet if prior testing has been performed on the specimen. This approach cannot be used for tests that might alter the gradation of the soil, such as Atterberg Limits.

9.2.3 *Intact Tube Samples*—To obtain a sieve analysis specimen from an intact tube sample, extrude either the entire sample, or a portion. Observe and estimate the maximum particle size. Use moist procedure (see 10.4.1) to obtain the necessary specimen.

9.2.4 *Samples from Prior Testing*—Frequently, after strength, hydraulic conductivity, consolidation or other testing has been completed, that specimen or a portion of it (from water content) is used for a sieve analysis specimen. The entire specimen can be used or split using the most appropriate procedure for specimen selection (moist or oven dried). If the specimen mass is less than required according to Table 2, note that the specimen is undersized on the data sheet. There may be conditions when it is undesirable to test the entire specimen due to the nonhomogeneity of the specimen. If there are layers in the specimen, it may be necessary and more useful to determine the gradation of individual layers.

10. Specimen

10.1 *General*—This section is separated into four parts. The mass requirement for the specimen is given in the first part (*Minimum Mass Requirement*). In the second part on *Selection of Sieving Procedure*, the determination of which sieving procedure applies, single sieve-set or composite sieving, is explained. In the third part on *Specimen Procurement*, an overview of the three applicable procedures (moist, air dried and oven dried) for use in obtaining a specimen from the sample and processing it for sieving is given. Following this overview is a discussion about special considerations relating to soils that readily segregate. In the fourth part on *Specimen Procurement and Processing Requirements*, details are given on how the above moist, air-dried and oven-dried procedures are to be applied to obtain a specimen(s) and prepare it for single sieve-set or composite sieving.

10.2 *Minimum Mass Requirement*—The minimum dry mass needed for a sieve analysis specimen is based on the maximum particle size in the sample and the test method (Method A or B) used to record the data. Based on the estimated maximum particle size, use Table 2 to determine the minimum mass of the specimen in g or kg.

10.3 *Selection of Sieving Procedure*—As shown in Fig. 2, the first decision step in this test method is to estimate the maximum particle size contained in the sample and then determine, based on the assigned Method (A or B), if the single sieve-set sieving or composite sieving procedure is to be used.

10.3.1 *Single Sieve-Set Sieving*—For Method A, this procedure applies to samples having a maximum particle size equal to or less than 9.5 mm (⅜-in. sieve). For Method B, this procedure applies to samples having a maximum particle size equal to or less than 4.75 mm (No. 4 sieve). However, if the material is ***not*** relatively well graded, then these acceptable maximum particle sizes may be smaller. If Method B is assigned and the sample has a maximum particle size larger than 4.75 mm, then this non-conformance should be noted on the data sheet and if necessary, inform the requesting authority. In addition, switch to Method A and if necessary, composite sieving.

10.3.1.1 Single sieve-set sieving ***could*** apply to samples having a maximum particle size up to 19.0 mm (¾-in. sieve) or possibly the 25.4 mm (1-in. sieve); providing Method A applies and the mass of the specimen meets the requirements presented in Table 2. In addition, it depends on the gradation of the sample, the size (diameter) of sieves being used, and if the tester wants to sieve the specimen in portions.

10.3.2 *Composite Sieving*—This procedure applies to samples having a maximum particle size equal to or greater than 19.0 mm (¾-in. sieve), unless 10.3.1.1 applies.

10.4 *Specimen Procurement*—This test method presents three procedures to obtain a representative specimen from the sample (moist, air-dried and oven-dried). In these procedures, the terms moist, air-dried or oven-dried refer to the condition of the material or sample as it is being processed to obtain the specimen. Additional guidance for splitting material to obtain a representative portion (specimen) using a splitter, quartering or moist stockpile sampling (Practice C702, Methods A, B and C, respectively) is given in Annex A2.

10.4.1 *Moist Procedure*—The sample is processed and split using moist stockpile sampling or quartering, if needed, in a moist, as-received state to obtain a representative specimen, unless the material is excessively wet or dry. This procedure is the preferred method for soils that readily segregate in a dry state such as coarse-grained soils with or without fines, or fine-grained soils containing coarse-grained particles, see 10.4.4. In addition, it is the preferred method for any sample containing soil whose properties are altered due to drying, and testing to determine those properties is necessary. These soil types may include most organic soils; many highly plastic fine-grained soils; tropical soils; and soils containing halloysite. Examples of such testing may include compaction, Atterberg Limits, specific gravity, and gradation by sedimentation. For samples requiring composite sieving, the sample typically becomes the specimen and requires additional processing as covered in 10.5.2.

10.4.2 *Air-Dried Procedure*—The sample is air dried, and then processed and split, if needed, using only a splitter to obtain the required specimen. The specimen is oven dried, washed, re-dried and then sieved. For samples requiring composite sieving, the sample typically becomes the specimen and requires additional processing as covered in 10.5.5.

10.4.3 *Oven-Dried Procedure*—The sample is oven dried, and then processed and split using only a splitter, if needed, to obtain the required specimen. The specimen is washed, re-dried, and then sieved. For samples, especially large ones requiring composite sieving and other testing, this procedure is typically not practical and shall not be used for soil types mentioned in 10.4.1.

10.4.4 *Discussion on Segregating Soils*—There are some special considerations relating to soils that readily segregate (such as gravels and sands, with or without fines). Experience gained from the ASTM Reference Soils and Testing Program and obtained at AASHTO Materials Reference Laboratory (AMRL) has clearly demonstrated the following conclusions. When dealing with soils that readily segregate and are in an air-dried or oven-dried state, the splitting processes (Practice C702, Method A) cannot be used more than a few times to obtain a representative specimen. The resulting specimen will have less fine sand and finer particles than the sample. This standard specifies when using a splitter, there cannot be more than two splitting operations (splits) to obtain the specimen. This number is based on judgment. There will be cases when more or less splits would be appropriate; however, use extreme caution in selecting more than two splits. For referee testing two splits cannot be exceeded. The method to obtain representative specimens from these soils requires that the soils be in a moist state. The water content should optimize bulking or be slightly wetter than the saturated surface-dry condition. This water content is to the point that the surface of the soil should look slightly wet but there are no signs of free water exiting the soil. This will reduce the potential for particle segregation and loss. The sample can be mixed and readily scooped/shoveled to obtain representative portions of the material (Practice C702, Method C, see A2.1.3). This procedure is especially useful if the maximum particle size is less than about 19.0 mm (¾-in. sieve).

10.5 *Specimen Procurement and Processing Requirements:*

10.5.1 *Moist Procedure, Single Sieve Set Sieving*—If single sieve-set sieving applies, as determined in 10.3, then either select the whole sample or split the sample after it is mixed in the as-received condition, unless it is too dry or wet for processing to obtain a representative specimen, see 10.5.1.2.

10.5.1.1 If the sample contains standing water or is very wet; then it may be dried back to a moist state, as defined in 10.4.1, 10.4.4, or A2.1.3, by air-drying or oven-drying (60°C). If oven drying is used, the sample is placed in a low temperature, drying oven (not to exceed 60°C) and mixed frequently to avoid excessive drying of any portion of the sample. If the sample is too dry; then water can be added (preferably by spraying) while the sample is being mixed to a moist state.

10.5.1.2 After mixing, obtain a representative specimen having the required mass (Table 2) by taking one or more scoops from the sample. The number of scoops shall increase as the mass of the specimen increases and come from various locations, and each scoop shall have about an equal mass, see A2.1.3. Place all the material in the scoop into the specimen container of known mass (g or kg). In this process, do not attempt to obtain an exact mass or increase the specimen size by adding very small amounts of material. For relatively well-graded coarse-grained soils, especially relatively clean ones containing gravel and coarse sand; do not add material by shaking it off the edge of the scoop. All of these processes could result in altering the gradation of the specimen. Oven dry the specimen (110 ± 5°C), see Notes 7 and 8. Record the identification of the specimen container and the mass (g or kg) of the container on the data sheet. Proceed to Section 11 on *Procedure (Sieving)*.

NOTE 7—For non-referee testing, it is acceptable practice to determine the oven-dried mass of a specimen or subspecimen, based on its moist mass and water content determined to the nearest 1 % for Method A or 0.1 % for Method B.

NOTE 8—This procedure for selecting material from a sample is basically the same as that presented in Practice C702, Method C—Miniature Stockpile Sampling (Damp Fine Aggregate Only) and summarized in A2.1.3.

10.5.2 *Moist Procedure, Composite Sieving*—For composite sieving, typically the whole sample becomes the specimen. If splitting is needed, obtain a representative portion by either the moist stockpile sampling procedure, as described in 10.5.1.2 or quartering (see A2.1.2). For an overview of the composite sieving method, refer to Fig. 2 through Fig. 4(b). In composite sieving, the following information must be obtained:

(a) The oven-dried mass of the coarser portion retained on designated separating sieve, CP,M_d in g or kg,

(b) The moist mass of the finer portion passing the designated separating sieve, FP,M_m in g or kg,

(c) The water content of a subspecimen obtained from the finer portion, w_{fp} in %,

(d) The calculated oven-dry mass of the finer portion, FP,M_d in g or kg, and

(e) The oven-dry mass of the subspecimen obtained from the finer portion for sieving over the finer sieve set, $SubS,M_d$ in g or kg.

10.5.2.1 If necessary, adjust the moisture condition of the material by drying or adding water as described in 10.5.1.1.

10.5.2.2 Select a designated separating sieve following the guidance given in 9.2.1 on *Bulk Samples* and Note 9. Process the specimen over this sieve. Manually or mechanically shake, or wiggle the finer portion through the sieve and collect both the coarser and finer portions. Remove any large conglomerations from the designated separating sieve and break them into individual particles or into conglomerations that are smaller than the openings in the designated separating sieve. Return the soil to the designated separating sieve and continue processing. Do not apply pressure that could damage the sieve. If fines are adhering to the coarser particles, scrape or brush these larger particles and dislodge the fines. If the fines are adhering into large clumps, use knives or spatulas to cut the clumps into chucks that will pass the designated separating sieve.

NOTE 9—Smaller cloth size of the designated separating sieve increases the difficulty in processing the material and having a limited amount of the fines adhering to the retained particles. In addition, selection of the designated separating sieve size may be based on ease of separating the specimen, additional testing to be performed, or convenience. For very plastic, clayey materials, it is easier to select a larger designated separating sieve. For materials that need compaction testing using either D698 or D1557, it is easiest to use the sieve (either No. 4 (4.75 µm), ⅜ in. (9.5 mm) or ¾ in. (19.0 mm)) necessary for the compaction method. Some laboratories are equipped with two sets of mechanical sieve shakers depending on size range, and, hence, the selection would be based on the equipment. There can be more than one designated separating sieve used in composite sieving, because the first subspecimen can be split again to obtain a second subspecimen.

10.5.2.3 *Coarse Portion Acceptable Loss* (CP_L)—It is usually not possible to remove all the fines (particles that would pass the designated separating sieve) adhering to the retained coarser particles. For the finer portion to be representative, the amount adhering to the retained coarser particles has to be less than 0.5 % of the dry mass of the specimen (S,M_d), see Note 9. If it appears that the material adhering to the retained portion will exceed the 0.5 % criterion, then the retained portion must be washed using a minimum amount of water and the washings added to the portion passing the designated separating sieve. The actual value will be determined at the end of the test.

10.5.2.4 Place the coarser portion in a suitable container of known mass (g or kg) and oven dry it (110 ± 5°C). Record the container identification and mass on the data sheet. If the water content of the coarser portion is needed (for example, to report the as received condition), determine it in accordance with Test Method D2216. Record the oven dry mass of the coarser portion, CP,M_d in g or kg.

10.5.2.5 Determine and record the moist mass (g or kg) of finer portion, using a balance meeting the requirements given in 6.4 and 11.2. Depending on the size of this portion, this mass determination can be done in increments as the material is being processed or after it has been processed. Record this moist mass as FP,M_m in g or kg.

10.5.2.6 Mix the moist finer fraction and obtain a representative subspecimen for both a water content determination and sieving using the moist stockpile sampling procedure, see 10.5.1.2. The finer portion subspecimen shall have a mass meeting the requirements given in Table 2. Record the container identification, mass of the container, and mass of the container plus moist material representing the finer portion subspecimen. The balance used shall meet or exceed the requirements of Test Method D2216 for water contents determined to the nearest 1 % or better.

10.5.2.7 Oven-dry the subspecimen in the oven at 110 ± 5°C. Calculate and record the water content, w_{fp}. Determine and record the dry mass of the subspecimen as $SubS,M_d$ in g or kg. If this subspecimen requires a second separation, (see Fig. 4(a) and Fig. 4(b)—composite sieving with double separation) processing the second subspecimen will be performed later (see 11.6).

10.5.2.8 Determine the dry mass of the specimen (coarser portion plus finer portion) in g or kg, see 12.4, and proceed to Section 11 on *Procedure (Sieving)*.

10.5.3 *Air Dried Procedure, General*—This method requires the use of a splitter to obtain a specimen from a sample that has been air-dried, unless the whole sample is tested. Therefore, this procedure can only be used for smaller samples in which no more than two splitting processes will be necessary, see 10.4.4. Typically, this procedure would only be used for soils coming from an arid region in which the soil will become air-dried and when other testing requires an air-dried condition.

10.5.3.1 Depending on the size of the sample, place the material either on a tray(s)/pan(s), smooth tarp/plastic sheet/ etc. or sealed-smooth floor (prevent loss of fines) and air-dry. Alternatively, an oven not exceeding 60°C may be used. Upon the completion of air-drying; place the material into either a container or pile. During this process, break apart any noticeable aggregations of soil particles. This can be done by hand or using a mortar and rubber-covered pestle or similar method that does not break the individual particles.

10.5.4 *Air Dried Procedure, Single Sieve-Set Sieving*—If this applies, as covered in 10.3; then either test the whole sample, noting its mass cannot be too large (Table 2) or after mixing, obtain a representative specimen having the required mass (Table 2) using a splitter and noting the above requirements and those in Annex A2, Sample to Specimen Reduction Methods, A2.1 and A2.1.1.

10.5.4.1 Place the specimen in a container of known mass (g or kg) and oven-dry the material at 110 ± 5°C. Record the identification of the specimen container, and mass of the container on the data sheet. Determine and record the dry mass of the specimen as S,M_d in g or kg. For non-referee testing, this dry mass may be based on an auxiliary water content of similar air-dried material (see Note 7).

10.5.4.2 Proceed to Section 11 on *Procedure (Sieving)*.

10.5.5 *Air Dried Procedure, Composite Sieving*—If composite sieving applies, as determined in 10.3, follow the moist procedure, as outlined in 10.5.2 through 10.5.2.8 to obtain the specimen and process it for composite sieving, except for the following:

(a) The sample is air-dried prior to any processing, see 10.5.4.1.

(b) The moist masses become air-dried masses.

(c) The water content of the coarser portion is not applicable.

(d) To obtain the subspecimen from the finer portion, the applicable guidance given in 10.5.3 shall be followed instead of that given in 10.5.2.6.

10.5.5.1 Proceed to Section 11 on *Procedure Sieving*).

10.5.6 *Oven-Dried Procedure, General*—This method requires the use of a splitter to obtain a specimen from a sample that has been oven-dried, unless the whole sample is tested. Therefore, this procedure can only be used for smaller samples in which no more than two splitting processes will be necessary, see 10.4.2 and 10.4.4. This procedure shall only be used when other testing is not necessary or needed, see 1.8 and 10.4.1. See 10.5.2 for comments on composite sieving.

10.5.6.1 Place the sample on a tray(s)/pan(s) and oven dry at 110 ± 5°C overnight or until thoroughly dry, see Test Method D2216. Upon the completion of drying; place the material into either a container or pile. During this process, break apart any noticeable aggregations of soil particles. This can be done by hand or using a mortar and rubber-covered pestle or similar method that does not break the individual particles.

10.5.7 *Oven Dried Procedure, Single Sieve-Set Sieving*—If this applies, as covered in 10.3; then either test the whole sample, noting its mass cannot be too large (Table 2) or after mixing, obtain a representative specimen having the required mass (Table 2) using a splitter and noting the above requirements and those in Annex A2, Sample to Specimen Reduction Methods, A2.1 and A2.1.1. Record the identification of the specimen container, and mass (g or kg) of the container on the data sheet. Determine and record the dry mass of the specimen as S,M_d in g or kg.

10.5.7.1 Proceed to Section 11 on *Procedure (Sieving)*.

10.5.8 *Oven Dried Procedure, Composite Sieving*—If composite sieving applies, as determined in 10.3, procure the specimen following the applicable guidance given in 10.5.4 through 10.5.4.2. Double check that the specimen's mass and its container has been determined and recorded. Select a designated separating sieve following the guidance given in 9.2.1 and Note 9. Process the specimen over this sieve following the applicable guidance given in 10.5.2.2 and 10.5.2.3.

10.5.8.1 Record the oven-dry mass of the coarser portion, CP,M_d in g or kg.

10.5.8.2 Mix the finer portion and obtain a representative subspecimen having the required mass (Table 2) using a splitter, see requirements given in 10.4.4. Record the container identification, mass of the container, and mass of the container plus dry material representing the finer-portion subspecimen. Calculate and record the dry mass of the subspecimen, $SubS,M_d$ in g or kg.

10.5.8.3 Proceed to Section 11 on *Procedure (Sieving)*.

11. Procedure (Sieving)

11.1 *General*—There are several different ways to determine the percent passing, since there are several different approaches to determine the amount of material retained on each sieve in a given sieve set. As previously stated, the procedure presented in this test method is to determine and record the mass of the cumulative material retained upon any given sieve within any given sieve set, since it is the easiest approach to present. However, this does not mean that other approaches are in nonconformance with this test method. One alternate approach would be to determine the amount of material retained on each sieve within a given sieve set, and then adjust the method of calculation to determine the percent passing.

11.1.1 The sieving process is usually accomplished using a mechanical sieve shaker (see 6.3); however, hand shaking is permissible, especially for the coarser sieves (larger than about the ¾-in. (19.0-mm). For referee testing, a mechanical sieve shaker shall be used for the portion passing the ¾-in. (19.0-mm) sieve.

11.1.2 The proper gradation of a specimen cannot be obtained if one or more sieves are overloaded during the sieving process, see 11.3 on *Sieve Overloading*.

11.2 *Mass Measurements*—The following details supplement the requirements presented in 6.4 on *Balances*. Determine the mass of the specimens to a minimum of three significant digits for Method A or a minimum of four significant digits for Method B. For subspecimens, only Method A applies. Determine the mass (g or kg) of the cumulative material retained using a balance having the same readability or better as was used to determine the mass of the specimen or subspecimen, see Note 3. This balance does not have to be the same one used to determine the mass of the specimen.

11.3 *Sieve Overloading*—The overloading of a sieve occurs when too many particles are retained on a sieve such that all particles do not have an opportunity to reach a sieve opening a number of times during sieve shaking. To prevent sieve overloading, the quantity of material retained on an individual sieve must be less than or equal to that specified in Table 3.

11.3.1 To avoid overloading, it is often necessary to divide large specimens or subspecimens into several portions. Each portion would be sieved and the amount retained on each sieve would be recorded. Then, the masses retained on a given sieve from all the sieved portions would be added as explained in 11.4.5.2.

11.3.2 If overloading has occurred, the specimen or subspecimen must be re-sieved in several portions or using sieves having a larger area.

11.4 *Single Sieve-Set Sieving*—A summary of terms used in single sieve-set sieving is presented in Fig. 1(a) and Fig. 1(b) while Fig. 3 presents a flowchart of this sieving process.

11.4.1 *Specimen Mass*—Check that the following had been determined and recorded in accordance with Section 10; the dry mass of the specimen, the identification of the specimen container and the procedure used to obtain that specimen (moist, air-dried or oven-dried). Record this mass as S,M_d in g or kg.

11.4.2 *Specimen Dispersion*—Prior to washing the specimen on the No. 200 (75-µm) washing sieve, the specimen shall be dispersed by one of the following procedures. However, in no case shall a mechanical mixer (with metal blade) be used to disperse the soil, since such mixers have a tendency to degrade (breakdown) coarse-grained particles. Wrist action shakers or similar agitating devices are acceptable, see 6.14.

11.4.2.1 *Soaking without a Dispersant*—Cover the specimen (soil) with tap water and allow it to soak for at least 5 minutes. Longer soaking periods are typically needed as the amount of fines or the plasticity of the fines or both increases. During this soaking period, the soil and water can be agitated using a stirring rod, spatula, dispersion shaker or similar device to facilitate the dispersion process or to check that the soil is dispersed. If clumps of particles or clods are detected, then this method of dispersion is not effective (see Note 10) and proceed to 11.4.2.2. A dispersion shaker shall not be used for relatively clean coarse-grained soils (such as: GP, SP, GP-GM, SP-SM, SP-SC).

NOTE 10—It is not easy to evaluate effective dispersion. Use visual or manual means or both to detect clumps of particles that would indicate incomplete or ineffective dispersion.

11.4.2.2 *Soaking with a Dispersant*—In accordance with Section 7, add the sodium hexametaphosphate either directly (dry addition) or in solution. Follow the instructions in 11.4.2.1. If this method of dispersion is not effective, the ultrasonic water bath could be used or additional time allowed for dispersion.

11.4.2.3 *Using an Ultrasonic Water Bath*—This procedure may be used for soils that are difficult to disperse. Place the specimen and container in the ultrasonic water bath following the guidance given in 6.13. The water in the specimen container should contain dispersant. If the size of the specimen container is not appropriate to fit into the ultrasonic water bath, then transfer the specimen to a suitable one, noting that the specimen can be dispersed in portions.

11.4.3 *Washing Specimen*—At the end of the soaking-dispersion period, the fines (minus No. 200 (75-µm) sieve material) are removed by washing using this procedure or by following the applicable portions of Method B given in Test Method D1140. The apparatus used shall meet the requirements given in 6.1.2 and 6.2.

TABLE 3 Overloading Limits for Standard Sieve Set

Alternative Sieve Designation	Standard Sieve Designation	Number of Grain Layers on Given Sieve	Maximum Mass Retained on 200-mm (8-in.) Diameter Sieve, g[A]	Maximum Mass Retained on 305-mm (12-in.) Diameter Sieve, g	Maximum Mass Retained on 370- by 580-mm (14.6- by 22.8-in.) Sieve, g
3 in.	75 mm	0.8	2 700	6 100	18 000
2 in.	50 mm	0.9	2 000	4 500	13 000
1-½-in.	37.5 mm	0.9	1 500	3 400	10 000
1 in.	25 mm	1	1 100	2 500	7 000
¾ in.	19.0 mm	1	900	2 000	6 000
⅜ in.	9.5 mm	1.25	550	1 200	3 600
No. 4	4.75 mm	1.5	325	730	2 000
No. 10	2.00 mm	2	180	410	1 000
No. 20	850 µm	3	115	260	800
No. 40	425 µm	4	75	170	500
No. 60	250 µm	5	60	140	400
No. 100	150 µm	6	40	90	300
No. 140	106 µm	6	30	70	200
No. 200	75 µm	6	20	50	100

[A] For sieve sizes other than those listed above, determine the surface area of the sieve(s) cloth being used in m^2 and divide this number by 0.028 m^2 (the approximate surface area of a 200-mm or 8-in. diameter sieve). Then multiply this area ratio by the masses listed in this column to form a column of acceptable masses for the different sieve area of interest. Round these values, so the significant digits are similar to those presented.

11.4.3.1 *General Precautions*—Washing specimens larger than about 200 g should be done in increments. For masses containing particles coarser than No. 4 (4.75-mm) sieve, all of the material should ***not*** be placed directly on the washing sieve (No. 200 or 75-µm), especially for brass cloth. In this case, a coarser size sieve (No. 40 or larger) shall be inserted above the washing sieve. It is necessary to see through this coarser sieve to check if the washing sieve is clogging (often the No. 40 sieve obscures this view and a No. 20 (850 µm) sieve is a better choice).

11.4.3.2 *Transfer Specimen*—Transfer the dispersed specimen, or a portion of the specimen to the washing sieve or the coarser sieve inserted above the washing sieve by pouring or any means that prevents spillage. During this process, stop pouring if any material loss will occur due to clogging of the washing sieve, and unclog the washing sieve, see Note 11. After emptying the dispersed specimen container, wash any remaining material onto the washing sieve or the coarser sieve inserted above it using the spray nozzle, wash bottle, or similar method.

11.4.3.3 *Washing*—Wash the specimen (material) on the washing sieve by means of a stream of water from the spray nozzle. Continually check to see if the washing sieve has clogged (see Note 11). The velocity of the water shall not cause any splashing of the material out of the sieve. The water temperature shall remain close to room temperature (see 6.2). To facilitate the washing process, the retained material may be lightly manipulated by hand while it is against the side of the sieve or above it, taking care not to lose any retained material. A wash shaker may be used to aid in the washing process. No downward pressure should be exerted on the retained material or sieve cloth to avoid forcing particles through the sieve or causing damage to the sieve. When the coarser sieve is being used, remove it from above the washing sieve as soon as the coarser material is washed and transfer it to the specimen container (see 11.4.3.4). Continue washing the specimen on the No. 200 (75-µm) sieve until the wash water is clear.

NOTE 11—If clogging of the washing sieve occurs, lightly hand tap the side or the bottom of the washing sieve until it is unclogged. Another method to unclog the washing sieve is gently spray a small amount of water up through the bottom of the washing sieve, then use the tapping approach to assist in the drainage of wash water.

11.4.3.4 *Transfer Washed Specimen*—Using a washing process, return the portion retained on the washing sieve and coarser sieve, if used, to its original specimen container or new container of known mass in g or kg. This can be done by washing the retained material to one side of the sieve, by tilting the sieve and allowing the wash water to pass through the sieve. Then, slowly wash this material into the container using as little wash water as possible, such that water will not fill and overflow the container. If the container approaches overflowing, stop the transfer process and decant the clear water from the container. Decant as much water from the container as practical without losing any retained material, and dry to a constant mass in an oven at 110 ± 5°C. This drying period will most likely be shorter than the overnight period suggested in D2216, because the retained material does not contained any fines. After oven drying, allow the container to cool, determine and record the dry mass of the washed material, S_wM_d in g or kg.

11.4.4 *Dry Sieving*—Dry sieving is accomplished by sieving the oven-dried washed material over an appropriate sieve set using a mechanical sieve shaker for a standard shaking period (see 8.2) and in such a manner that prevents the overloading of any given sieve (see 11.3). Then, the cumulative material retained for each sieve within a sieve set by mass or cumulative mass retained is determined. Based on these measurements, the percent passing each sieve is determined. The following procedure assumes that a stack of 200-mm or 8-in. diameter sieves is being used. However, the use of other sieve sizes or configurations is not prohibited providing they meet the requirements given in Sections 6, 8, and this section.

11.4.4.1 *Sieve Set*—Assemble an appropriate stack of sieves from the standard set given in Table 1 and meeting the requirements given in 6.1. The largest sieve size shall be such that 100 % of the washed (sieving) material passes through it. Do not omit any standard sieves sizes between the largest sieve size and the No. 200 (75-µm) sieve, but it is permissible to include additional sieves. Assemble the stack of sieves with the largest sieve size at the top. Add the remaining sieves in descending sieve size. Add the pan on the bottom and the lid on the top on the sieve stack, if appropriate. If there are too many sieves to fit into the sieve shaker, it is permissible to separate this set into a coarser subset and a finer subset. It is also permissible to use “half height” sieves, see 6.1. Some sieves are designed to stack on top of each other, and other sieves are inserted like drawers into the shaker. Either type is acceptable.

11.4.4.2 *Mechanical Shaking*—Pour the dried washed material from its container onto the sieve at the top of the sieve stack. Then brush any material remaining in the container onto that sieve. The container should be close to the sieve to prevent spillage and creation of dust. Cover the stack of sieves with the lid, if applicable, and place the sieve set in the sieve shaker. Shake the sieve set for the standard shaking period established in 8.2 (using a timing device) for that sieve shaker and size sieve set. Avoid overloading the sieves, see 11.3. Upon completion of shaking, remove the sieve set for determination of the cumulative material retained for each sieve, as covered below.

11.4.5 *Cumulative Material/Mass Retained* (Hereafter referred to as cumulative mass retained.)

11.4.5.1 *First Sieve*—Remove the lid from the sieve set, verify that no material was retained on the top (largest size) sieve (record 0.0 g or kg in the cumulative mass retained column, CMR_N). If material is retained on the top sieve, determine and record its mass, CMR_N, in accordance with 11.2 in g or kg. Transfer that retained material to the next larger sieve size in the standard sieve set, see Table 1. Add the pan and lid and hand shake that sieve following the procedure given in 8.2.3 on *Hand Sieve Shaking*. Shake until either the entire retained material has passed that sieve or for about one minute. Verify that no material was retained on that sieve by recording 0.0 g or kg as appropriate. Transfer the contents of the pan to the cumulative mass container (see 6.6.3).

11.4.5.2 *Remaining Sieves*—Remove the next sieve and turn the sieve upside down such that the retained material falls onto the collection/transfer device (see 6.6.2) without spillage or creating dust. Any material remaining in the sieve may be gently removed using a sieve brush (see 6.7). Take care to avoid distortion or damage of the sieve cloth (see 6.7.1 through 6.7.6). Next transfer this retained material to the container (see 6.6.3) holding the cumulative mass retained, *CMRN*. Determine, in accordance with 11.2 and record the mass (g or kg) contained in this container, CMR_N. Continue in this manner for the remaining *Nth* sieves and pan.

11.4.5.3 When using the cumulative mass retained method, sieve-overloading problems are not immediately apparent, but they shall be checked for during this process, see 11.3. Conversely, when the data sheet lists the overloading masses and the mass on each sieve is recorded, any problems due to overloading will be immediately noticed. If overloading occurred, re-sieve the material in accordance with the instructions provided in 11.3.1. In the case where the sieving process is done in parts, such as to prevent overloading or overloading has occurred, then there is more than one set of partial cumulative mass retained determinations to be recorded and combined to determine the cumulative mass retained, CMR_N. This will require either special or multiple data sheets.

11.4.5.4 Proceed to Section 12 on *Calculations*.

11.5 *Composite Sieving, Single Separation*—Refer to Fig. 1(a) and Fig. 1(b) for the terms used in composite sieving and Fig. 4(a) for a flowchart of these sieving processes. When composite sieving is necessary, the following items requiring sieving were obtained during the processing of the specimen and identified on the data sheet, as covered in Section 10 on *Specimen*. These items are:

(a) The oven-dried mass of the portion retained on designated separating sieve; that is the coarser portion, CP,M_d in g or kg.

(b) The oven-dried mass of the subspecimen obtained from the finer portion, $SubS,M_d$ in g or kg.

11.5.1 *Coarser Portion*—If the coarser portion is clean (free of material finer than the designated separating sieve) or already washed (see 10.5.2.3), and the testing is not used as referee testing, the coarser portion will not need to be washed. It is permissible to consider the coarser portion to be clean if 0.5 % or less of that finer material (based on specimen's dry mass, S,M_d) would be or are removed from the coarser portion while sieving or washing, or both. Washing is not needed under these conditions. For referee testing, the coarser portion shall be washed.

11.5.1.1 *Dispersing and Washing*—Follow the applicable instructions provided in 11.4.2 to disperse the coarser faction and 11.4.3 to wash the coarser portion after dispersion, while noting the following:

(a) Soaking in water, will usually suffice,

(b) Washing is done on either the designated separating sieve used to separate the specimen into a coarser and finer portion, or another sieve of equal size (designation, see Table 1); and,

(c) During washing or the dispersion process fine particles may be brushed off coarser particles.

11.5.1.2 Return the retained washed portion to the same container and oven dry to a constant mass (110 ± 5°C). Determine and record the dry mass (g or kg) of the washed coarser portion, CP_wM_d, following the instructions provided in 11.2. The calculation of the acceptable percent loss during washing or sieving, or both of the coarser portion is covered in Section 12 on *Calculations*, 12.5.1.3. This calculation is performed after the sieving of the coarser portion. If CF_L is greater than 0.5 %, the sieve analysis is in nonconformance (unless the washings were added to the finer portion) and this factor shall be noted on the data sheet.

11.5.1.3 *Dry Sieving Coarser Portion*—Using this clean or washed coarser portion, follow the applicable instructions given in 11.4.4 (*Dry Sieving*) and 11.4.5 (*Cumulative Mass Retained*), while noting the finest sieve size in the coarser sieve set is the size of the designated separating sieve, ***not*** the No. 200 (75-µm) sieve. Determine and record these values of cumulative mass retained in the coarser sieve set and for each *Nth* sieve as CP,CMR_N in g or kg, Determine and record the mass of material contained in the pan, CP,MR_{pan} in g or kg. The calculation of the acceptable percent loss during washing or sieving, or both of the coarser portion is covered in Section 12 on *Calculations*, 12.5.1.3. If CF_L is greater than 0.5 %, the sieve analysis is in nonconformance and this factor shall be noted on the data sheet.

11.5.2 *Subspecimen from Finer Portion*—If the size of the designated separating sieve is equal to or larger than the ¾-in. (19.0-mm) sieve, then this subspecimen will have to be separated again, or washed and sieved in portions, see 10.3.1.1. If separation over a 2nd designated separation sieve is necessary, then additional processing and sieving is needed, as covered in 11.6.3. If a 2nd separation is ***not*** necessary (see Fig. 4(a)), then this subspecimen can be sieved as described below.

11.5.2.1 *Dispersing and Washing Subspecimen*—Wash the subspecimen following the applicable instructions provided in 11.4.2 to disperse the subspecimen and 11.4.3 to wash the subspecimen after dispersion. After oven drying, allow the container to cool, determine and record the dry mass of the washed material, $SubS_wM_d$ in g or kg.

11.5.2.2 *Dry Sieving Subspecimen*—Using the above dry washed subspecimen, dry sieve this material and determine the cumulative masses retained following the applicable instructions given in 11.4.4 through 11.4.5.3 and noting the following changes:

(a) The coarsest sieve size in the finer sieve set is the size of the designated separating sieve.

(b) For these cumulative mass retained values, they are identified as fractional cumulative mass retained on each *Nth* sieve as $SubS,FCMR_N$ in g or kg.

(c) There should not be any material retained on the coarsest sieve in the finer sieve set. Retained material indicates that the specimen was not split properly or there is a difference in openings in the sieve cloth between the designated separating sieve and the one in the finer sieve set. If the mass of material retained on this sieve, $SubS,MR_{first}$, is equal to or less that 2 % of the subspecimen's mass, $SubS,M_d$, then record the mass in g or kg. There might not be an identifiable space provided on the data sheet for this value, especially in composite sieving with double separations. In that case, record the value in the margin next to the appropriate sieve size.

(d) If the mass retained on this sieve exceeds 2 %, then the sieve analysis is in nonconformance and this factor noted on the data sheet, but record that value and determine the remaining $SubS,FCMR_N$ values. If this continually occurs, then the testing laboratory shall first review its splitting methodology for errors, and then verify that the sieve cloth of the sieves involved meet the full requirements of Specification E11, or replace those sieves with new ones.

11.5.2.3 Proceed to Section 12 on *Calculations*.

11.6 *Composite Sieving, Double Separation*—The 1st subspecimen will be processed over a 2nd designated separating sieve for composite sieving with double separation. See Fig. 1(a) and Fig. 1(b) for summary and flowchart of terms used and Fig. 4(a) and Fig. 4(b) for a flowchart of these sieving processes.

11.6.1 *Separating 1st Subspecimen*—Select the size of the 2nd designated separating sieve; usually this sieve size is the ⅜-in. (9.5-mm), No. 4 (4.75 mm), or No. 10 (2.00-mm) sieve. When selecting this sieve, remember that as the size of the designated separating sieve decreases, it is more difficult to obtain a representative 2nd subspecimen and meet the 0.5 % criterion on loss of material during washing and sieving of the 2nd coarser portion (see 11.6.2).

11.6.1.1 Sieve the 1st subspecimen over the 2nd designated separating sieve using the mechanical sieve shaker and appropriate standard shaking period and in increments to prevent sieve overloading. Separately collect the retained and passing portions.

11.6.1.2 Closely check the retained material for material finer than the 2nd designated separating sieve, if noted, they can be broken up by hand or by using a mortar and rubber-covered pestle. Re-sieve that material over the 2nd designated separating sieve by hand sieving (see 8.2.3) and add the retained and passing portions to the appropriate container.

11.6.2 *Dispersing and Washing 2nd Coarser Portion*—Recheck the retained material, if the amount of adhering particles appears to exceed 0.5 % of $1^{st}SubS,M_d$ then wash those fines into the container containing the second 2nd finer portion (that is, the material passing the 2nd designated separating sieve) and oven dry (110 ± 5°C) both portions ($2^{nd}CP_wM_d$ and 2nd finer portion). If the amount of finer material appears to be equal or less that this 0.5 % criterion; then determine and record the dry mass, $2^{nd}CP,M_d$ in g or kg and then sieve the 2nd coarser portion using the 2nd coarser sieve set. In addition, if this 2nd coarser portion is washed and it appears the adhering particles will not exceed 0.5 %, then the washings do not have to be added to the 2nd finer portion. For referee testing, the 2nd coarser portion has to be washed following the applicable instructions given in 11.5.1.1, while noting the following.

11.6.2.1 Determine and record the oven-dry mass (g or kg) of the 2nd coarser portion before and after washing as $2^{nd}CP,M_d$ and $2^{nd}CP_wM_d$, respectively.

11.6.2.2 The calculation of acceptable loss on washing criterion of 0.5 % is now based on the mass (g or kg) of the 1st subspecimen, $1^{st}SubS,M_d$. This calculation is covered in Section 12 on *Calculations*, 12.6.2.3.

11.6.3 *Dry Sieving 2nd Coarser Portion*—Using this clean or washed 2nd coarser portion, follow the applicable instructions given in 11.4.4 (*Dry Sieving*) and 11.4.5 (cumulative mass retained), while noting the following.

11.6.3.1 The coarsest and finest sieve sizes in this 2nd coarser sieve set are the size of the 1st and 2nd designated separating sieve, respectively.

11.6.3.2 The mass (g or kg) of material retained on the coarsest sieve shall not exceed 2 % of the dry mass of the 1st subspecimen; see 11.5.2.2, Items c and d.

11.6.3.3 The mass of the material in the pan, plus loss on washing, if applicable, cannot exceed 0.5 % criterion.

11.6.3.4 The calculations related to the 2nd coarser portion are covered in 12.6.2.1 through 12.6.2.5.

11.6.4 *2nd Subspecimen*—Using a splitter (see 6.9 and 10.4.4), split the 2nd finer portion to obtain the 2nd subspecimen having a mass (g or kg) meeting the requirements given in Table 2. Following the instructions provided in 11.2, determine and record the mass of the 2nd subspecimen as $2^{nd}SubS,M_d$ in g or kg.

11.6.4.1 *Dispersing and Washing 2nd Subspecimen*—Wash the 2nd subspecimen following the applicable instructions provided in 11.5.2.1. After oven drying, allow the container to cool, determine and record the dry mass of the washed material, $2^{nd}SubS_wM_d$ in g or kg.

11.6.4.2 *Dry Sieving 2nd Subspecimen*—Using this oven-dried, washed 2nd subspecimen; dry sieve this material and determine the 2nd fractional cumulative masses (g or kg) retained following the applicable instructions given in 11.5.2.2, while noting the following:

(a) The coarsest sieve size in this finer sieve set is the size of the 2nd designated separating sieve.

(b) For these cumulative masses retained values, they are identified as 2nd fractional cumulative mass retained for each *Nth* sieve as $2^{nd}SubS,CMR_N$ in g or kg.

(c) As stated in 11.5.2.2, Item c and d, there should not be any material retained on the coarsest sieve in this finer sieve set and the same 2 % criterion is applicable, except the mass (g or kg) of the 2nd subspecimen ($2^{nd}SubS,M_d$) is used instead of the 1st subspecimen ($1^{st}SubS,M_d = SubS,M_d$).

11.6.4.3 Proceed to Section 12 on *Calculations*, 12.6.3 through 12.6.4.2.

12. Calculations

12.1 *General*—Refer to Fig. 1(a) and Fig. 1(b) for the typical terms used in sieving and data reduction. The cumulative mass retained (*CMR*) or fractional cumulative mass retained (*FCMR*) recorded for each *Nth* sieve, CMR_N or $FCMR_N$, will be used to calculate a percent passing (*PP*) each *Nth* sieve, PP_N. These results will be tabulated and may be presented graphically. Depending on the assigned/selected method, the results are rounded and presented to either the nearest 1 % (Method A) or 0.1 % (Method B), except for composite sieving, when only Method A applies. The graphical presentation is a plot of percent passing versus log of particle size (mm). The individual points should be connected by a smooth curve.

12.1.1 In the calculations presented below the masses can be in either g or kg. All sieving masses are dry (oven), unless noted otherwise.

12.1.2 In performing calculations needing intermediate values, the data sheet does not have to provide spaces for those values. For example, when calculating the percent finer, the needed intermediate calculation of cumulative percent retained does not have to be recorded.

12.1.3 The equations are given for calculation of percent passing. To calculate the percent retained necessary in determining the precision of this test method, see 14.1.2.1.

12.1.4 A summary of the symbols used below, along with their definition is given in the Annex A1 on Symbols.

12.2 *Sieve Overloading*—The details for determining when a sieve(s) is overloaded during the sieving process is given in 11.3. The only calculation involved is to determine the dry mass of material retained on each *Nth* sieve in g and then compare that value with the maximum allowable value given in Table 3. When the *CMR* sieving process is used, the dry mass retained on the *Nth* sieve, MR_N, is as follows:

$$MR_N = CMR_N - CMR_{N-1} \tag{1}$$

where:

MR_N = mass retained on the *Nth* sieve, g,
CMR_{N-1} = cumulative mass retained on the sieve above the *Nth* sieve, g, and
CMR_N = cumulative mass retained on the *Nth* sieve (in this case the sieve being checked for overloading), g.

12.3 *Single Sieve-Set Sieving, Percent Passing*—For single sieve-set sieving (specimens not requiring composite sieving), calculate the percent passing each *Nth* sieve as follows:

$$PP_N = 100\left(1 - CMR_N / S,M_d\right) \tag{2}$$

where:

PP_N = percent passing the *Nth* sieve, %,
CMR_N = cumulative mass retained on the *Nth* sieve; that is, the mass of material retained on the *Nth* sieve and those above it, g or kg, and
S,M_d = dry mass of the specimen, g or kg.

12.4 *Composite Sieving, Mass of Specimen*—Calculate the dry mass of the specimen, S,M_d as follows:

$$S,M_d = CP,M_d + \left(\frac{FP,M_m}{1 + \frac{w_{fp}}{100}}\right) \tag{3}$$

where:

S,M_d = dry mass of the specimen, g or kg,
CP,M_d = dry mass of the coarser portion, g or kg,
FP,M_m = moist or air-dried mass of the finer portion, g or kg, and
w_{fp} = water content of the finer portion, %.

12.5 *Composite Sieving, Single Separation*—The percent passing the coarser portion (*CP*) is calculated using the same approach as for single sieve-set sieving. For the subspecimen obtained from the finer portion; a composite sieving correction factor (*CSCF*) is required to convert the subspecimen's fractional percent passing to the specimen's percent passing, since only a portion of the specimen is sieved. Multiple approaches can be used to make this correction and they are in conformance with this test method, provided the calculated results are the same. In the presentation below, the percent passing values are identified related to the portion being dry sieved, such as CP,PP_N and $SubS,PP_N$; however, this distinction is not necessary on the data sheet. This approach is being done to allow the user to easily distinguish which portion is being calculated to determine the percent passing the specimen.

12.5.1 *Composite Sieving, Coarser Portion (CP):*

12.5.1.1 *CP, Percent Passing*—Calculate the percent passing each *Nth* sieve in the coarser sieve set as follows:

$$CP,PP_N = 100\left(1 - \left(CP,CMR_N / S,M_d\right)\right) \tag{4}$$

where:

CP,PP_N = specimen's percent passing the *Nth* sieve in the coarser sieve set while sieving the coarser portion of the specimen, %, and
CP,CMR_N = coarser portion's cumulative mass retained on the *Nth* sieve in the coarser sieve set, g or kg.

12.5.1.2 *CP, Composite Sieving Correction Factor (CSCF)*—The *CSCF* is equal to the percent passing the designated separating sieve size in the coarser sieve set (that is, the last/bottom sieve in that set). This value, CP,PP_{last}, shall be calculated and recorded to at least one more digit than required (nearest 0.1 %) to reduce rounding errors.

12.5.1.3 *CP, Acceptable Loss During Washing and Sieving*—Calculate the percent loss of the coarser portion during washing or sieving, or both as follows:

$$CP_L = 100\left(\left(\left(CP,M_d - CP_wM_d\right) + CP,MR_{pan}\right) / S,M_d\right) \tag{5}$$

where:

CP_L = percent of the coarser portion lost during washing and dry sieving, %,
CP,M_d = dry mass of the coarser portion, g or kg,
CP_wM_d = dry mass of the coarser portion after washing, g or kg, and
P,MR_{pan} = dry mass retained in the pan after dry sieving the coarser portion, g or kg.

The percent loss is acceptable if the value of CP_L is less than or equal to 0.5 %.

12.5.2 *Composite Sieving, Subspecimen (finer portion):*

12.5.2.1 *Percent Passing, Specimen (combined coarser and finer portions)*—In the approach presented, the fractional percent passing the subspecimen is corrected by the *CSCF* so it represents the percent passing the specimen. Calculate the percent passing each *Nth* sieve in the finer sieve set, $SubS,PP_N$ as follows:

$$\begin{aligned} SubS,PP_N = CSCF \times SubS,FPP_N = CSCF\,\big(1 \\ - \left(SubS,FCMR_N / SubS,M_d\right)\big) \end{aligned} \tag{6}$$

where:

$SubS,PP_N$ = specimen's percent passing the *Nth* sieve in the finer sieve set, %,
$SubS,FPP_N$ = subspecimen's fractional percent passing the *Nth* sieve in the finer sieve set, decimal (*not in %*),

$SubS,FCMR_N$ = subspecimen's fractional cumulative mass retained on the *Nth* sieve in the finer sieve set, g or kg, and

$SubS,M_d$ = dry mass of the subspecimen, g or kg.

12.5.2.2 *Subspecimen, Acceptable Fractional Percent Retained*—As covered in 11.5.2.2, there should not be any material retained on the first/top sieve, same size as the designated separating sieve, in the finer sieve set; however, when there is, the fractional percent retained shall not exceed 2 %. Calculate the fractional percent retained on the first sieve as follows:

$$SubS,FCPR_{first} = 100\left(SubS,FCMR_{first}/SubS,M_d\right) \tag{7}$$

where:

$SubS,FCPR_{first}$ = fractional cumulative percent retained on the first sieve (sieve size equal to the designated separating sieve) in the finer sieve set, %, and

$SubS,FCMR_{first}$ = fractional cumulative mass retained on the first sieve in the finer sieve set, g or kg. (This mass is actually the mass retained since there is not any sieve above it.)

12.5.2.3 *Percent Passing, Acceptance Criterion*—If material is retained on the designated separating-sieve size in the fine sieve set, then there will be two percent passing values for the same sieve size. If this occurs, the percent passing value from the coarser sieve set shall be the accepted value in determining the gradation of the specimen.

12.5.3 *Finer Portion, Percent Passing (optional)*—As mentioned in 9.2.1, there are cases where the gradation of the finer portion might be necessary, especially when other testing, such as compaction, are performed. In this case, the fractional percent passing the subspecimen, $SubS,FPP_N$ in %, represents the percent passing the finer portion, FP,PP_N. Calculate those values as follows:

$$FP,PP_N = 100\left(1 - \left(SubS,FCMR_N/SubS,M_d\right)\right) \tag{8}$$

where:

FP,PP_N = finer portion's percent passing the *Nth* sieve, %.

12.6 *Composite Sieving, Double Separation*—The methodology for these calculations is similar to that for calculating composite sieving with single separation, the only basic changes are the addition of new terms, see Fig. 1(a) and Fig. 1(b), and one additional set of calculations relating to the 2nd subspecimen. Therefore, review those figures and the comments presented in 12.5.

12.6.1 *1st Coarser Portion*—The percent passing, *CSCF* and acceptable loss calculations are the same as covered above, see Composite Sieving-Coarser Portion, 12.5.1, except the prefix 1st is added to all terms and symbols.

12.6.2 *1stSubspecimen*—In this case, the subspecimen is not sieved in its entirety, but is separated into a coarser and finer portion (2nd coarser portion and 2nd finer portion). The needed calculations associated with sieving the 2nd coarser portion and associated components are given below.

12.6.2.1 *Percent Passing, 2nd Coarser Portion*—Calculate the percent passing each *Nth* sieve in the 2nd coarser sieve set as follows:

$$2^{nd}CP,PP_N = 1^{st}CSCF \times 2^{nd}CP,\ FPP_N = 1^{st}CSCF\left(1 - \left(2^{nd}CP,CMR_N/SubS,M_d\right)\right) \tag{9}$$

where:

$2^{nd}CP,PP_N$ = specimen's percent passing the *Nth* sieve in the 2nd coarser sieve set while sieving the coarser portion of the 1st subspecimen, %,

$1^{st}CSCF$ = 1st composite sieving correction factor, which is equal to the percent passing the designated separating sieve size in the 1st coarser sieve set while sieving the coarser portion of the specimen, %,

$2^{nd}CP,\ FPP_N$ = 2nd coarser portion's fractional percent passing the *Nth* sieve in the 2nd coarser sieve set, decimal (*not in %*), and

$2^{nd}CP,CMR_N$ = 2nd coarser portion's fractional cumulative mass retained on *Nth* sieve in the 2nd coarser sieve set, g or kg.

12.6.2.2 *2nd Coarser Portion, Composite Sieving Correction Factor ($2^{nd}CSCF$)*—The $2^{nd}CSCF$ is equal to the percent passing the 2nd designated separating sieve size in the 2nd coarser sieve set (that is, the last/bottom sieve in that set) while sieving the coarser portion of the 1st subspecimen. This value, $2^{nd}CP,PP_{last}$, shall be calculated and recorded to at least one more digit than required (nearest 0.1 %) to reduce rounding errors.

12.6.2.3 *2nd Coarser Portion, Acceptable Loss on Sieving and Washing*—The calculation and acceptance criterion for the 2nd coarser portion are the same as covered above, see 12.5.1.3, except the prefix 2nd is added to the applicable terms and symbols, and the dry mass of the specimen is replaced by the dry mass of the 1st subspecimen, as shown in the following equation:

$$2^{nd}CP_L = 100\left(\left(\left(2^{nd}CP,M,_d - 2^{nd}CP_wM_d\right) + 2^{nd}CP,MR_{pan}\right)/1^{st}SubS,M_d\right) \tag{10}$$

where:

$2^{nd}CP_L$ = percent of the 2nd coarser portion lost during washing and dry sieving, %,

$2^{nd}CP,M,_d$ = dry mass of the 2nd coarser portion, g or kg,

$2^{nd}CP_wM_d$ = dry mass of the 2nd coarser portion after washing, g or kg, and

$2^{nd}CP,MR_{pan}$ = dry mass retained in the pan after dry sieving the coarser portion, g or kg.

12.6.2.4 *2nd Coarser Portion, Acceptable Fractional Percent Retained*—As covered in 11.6.3.2, there should not be any material retained on the first/top sieve, same size as the designated separating sieve, in the 2nd coarser sieve set; however, when there is, the fractional percent retained shall not exceed 2 % of the dry mass of the 1st subspecimen. Calculate the fractional percent retained on the first sieve as follows:

$$2^{nd}CP,FPR_{first} = 100\left(2^{nd}CP,FCMR_{first}/SubS,M_d\right) \tag{11}$$

where:

$2^{nd}CP,FPR_{first}$ = 1st fractional percent retained on the first sieve (sieve size equal to the designated separating sieve) in the 2nd coarser sieve set while sieving the coarser portion of the 1st subspecimen, %, and

$2^{nd}CP,FCMR_{first}$ = 1st fractional cumulative mass retained on the first sieve in the 2nd coarser sieve set, g or kg. (This mass is actually the mass retained since there is not any sieve above it.)

12.6.2.5 *Percent Passing, Acceptance Criterion*—If material is retained on the designated separating-sieve size in the 2nd coarser sieve set, then there will be two percent passing values for the same sieve size. If this occurs, the percent passing value from the 1st coarser sieve set shall be the accepted value in determining the gradation of the specimen.

12.6.3 *2nd Subspecimen*—The needed calculations associated with sieving the 2nd subspecimen are given below.

12.6.3.1 *Percent Passing, 2nd Subspecimen*—Calculate the percent passing each *Nth* sieve in the finer sieve set as follows:

$$2^{nd}SubS,PP_N = 2^{nd}CSCF \times 2^{nd}SubS,FPP_N = 2^{nd}CSCF\left(1 - \left(2^{nd}SubS,FCMR_N/2^{nd}SubS,M_d\right)\right) \qquad (12)$$

where:

$2^{nd}SubS,PP_N$ = specimen's percent passing the *Nth* sieve in the finer sieve set while sieving the 2nd subspecimen, %,

$2^{nd}CSCF$ = 2nd composite sieving correction factor, which is equal to the percent passing the 2nd designated separating sieve size in the 2nd coarser sieve set while sieving the coarser portion of the 1st subspecimen, %,

$2^{nd}SubS,FPP_N$ = 2nd subspecimen's fractional percent passing the *Nth* sieve in the finer sieve set, decimal (not in %),

$2^{nd}SubS,FCMR_N$ = 2nd subspecimen's fractional cumulative mass retained on the *Nth* sieve in the finer sieve set, g or kg, and

$2^{nd}SubS,M_d$ = dry mass of the 2nd subspecimen, g or kg.

12.6.3.2 *2nd Subspecimen, Acceptable Fractional Percent Retained*—As covered in 11.6.2.2, there should not be any material retained on the first/top sieve, same size as the designated separating sieve, in the finer sieve set; however, when there is, the fractional percent retained shall not exceed 2 %. Calculate the fractional percent retained on the first sieve as follows:

$$2^{nd}SubS,FPR_{first} = 100\left(2^{nd}SubS,FCMR_{first}/2^{nd}SubS,M_d\right) \qquad (13)$$

where:

$2^{nd}SubS,FPR_{first}$ = 2nd fractional percent retained on the first sieve (sieve size equal to the 2nd designated separating sieve) in the finer sieve set while sieving the 2nd subspecimen, %, and

$2^{nd}SubS,FCMR_{first}$ = 2nd fractional cumulative mass retained on the first sieve in the finer sieve set while sieving the 2nd subspecimen, g or kg. (This mass is actually the mass retained since there is not any sieve above it.)

12.6.3.3 *Percent Passing, Acceptance Criterion*—If material is retained on the 2nd designated separating-sieve size in the finer sieve set while sieving the 2nd subspecimen, then there will be two percent passing values for the same sieve size. If this occurs, the percent passing value from the coarser sieve set shall be the accepted value in determining the gradation of the specimen.

12.6.4 *1st Finer Portion, Percent Passing (optional)*—As mentioned in 9.2.1, there are cases where the gradation of the specimen's 1st finer portion might be necessary, especially when other testing, such as compaction, are performed. In this case, the fractional percent passing the 2nd coarser portion, $2^{nd}CP,FPP_N$ in %, is representative of the percent passing the 1st finer portion, $1^{st}FP,PP_N$, up to the 2nd designated separating sieve size. Calculate those values as follows:

$$1^{st}FP,PP_N = 100\left(1 - \left(2^{nd}CP,FCMR_N/SubS,M_d\right)\right) \qquad (14)$$

where:

$1^{st}FP,PP_N$ = 1st finer portion's percent passing the *Nth* sieve in the 2nd coarser sieve set while sieving the coarser portion of the 1st subspecimen, %.

While the $1^{st}FP,PP_N$ calculations associated with the 2nd finer portion or 2nd subspecimen are given below.

12.6.4.1 *2nd Finer Portion, Composite Sieving Correction Factor (optional)*—When the gradation of the 1st finer portion is needed and the 1st subspecimen is separated, then an additional composite sieving correction factor is necessary to convert the fractional percent passing the 2nd subspecimen to a percent passing which is representative of the 1st finer portion. This *CSCF* is identified as *FP,CSCF* and is equal to either the fractional percent passing the 2nd designated separating sieve size in the 2nd coarser sieve set, or the 1st finer portion's percent passing the last/bottom sieve in the 2nd coarser sieve set, FP,PP_{last}, as calculated above (see 12.6.4) and recorded to at least one more digit than required (nearest 0.1%) to reduce rounding errors.

12.6.4.2 *1st Finer Portion, Percent Passing for 2nd Subspecimen (optional)*—In this case, the 2nd fractional percent passing the finer sieve set, $2^{nd}SubS,FPP_N$ in % has to be corrected by the *FP,CSCF* (see 12.6.4.1) to represent the percent passing the finer portion, $1stFP,PP_N$. Calculate those values as follows:

$$1^{st}FP,PP_N = FP,CSCF\left(1 - \left(2^{nd}SubS,FCMR_N/2^{nd}SubS,M_d\right)\right) \qquad (15)$$

where:

$FP,CSCF$ = 1st finer portion's composite sieving correction factor, which is equal to the finer portion's percent passing the last/bottom sieve in 2nd coarser sieve set,%.

13. Report: Test Data Sheets(s)/Form(s)

13.1 The methodology used to specify how data are recorded on the test data sheet(s)/form(s), as given below, is covered in 1.13. If the test results (gradation) are reported in tabular or graphical format for other than the laboratory's data records, then those values have to be representative of the method used (Method A or B). The percent passing values must be rounded to the appropriate percentage before tabulating or plotting; that is, the nearest 1 % and 0.1 % for Method A and B, respectively. However, the laboratory's test data sheet(s)/form(s) do not have to meet this requirement, if the method used (Method A or B) is clearly identified.

13.2 Record as a minimum the following information (data):

13.2.1 Identification of the material being tested, such as project identification, boring number, sample number, depth, and test number.

13.2.2 Name or initials of person performing the test and date(s).

13.2.3 Visual classification of the soil being tested (estimate group name and symbol in accordance with Practice D2487).

13.2.4 Test method used (Method A, or B).

13.2.5 The procedure used to obtain the specimen(s) from the sample, such as moist, air dried, or oven dried, see 1.8 and Section 10.

13.2.6 If any soil or material was excluded from the specimen, describe the excluded material. If any problems were encountered, describe the problems.

13.2.7 Indicate if composite sieving was used and the size of the designated separating sieve(s). If material is retained on the designated separating sieve size in the finer sieve set, then document that the percent retained (*PR*) does not exceed the 2 % criterion (see 11.5.2.2, Item c and d; 11.6.3.2 and 11.6.4.2, Item c) on sieving those portion(s)).

13.2.8 Indicate if the ultrasonic bath or shaking apparatus or both were used during the dispersion process.

13.2.9 Any prior testing performed on specimen.

13.2.10 All mass measurements (to the appropriate significant digits or better).

13.2.11 Tabulation of percent passing (PP) for each sieve, preferably to either the nearest 1 % or 0.1 % in accordance with Method A or B, respectively, see 13.1. Note this percentage should have an extra digit associated with designated separating sieve sieves.

13.2.12 *(Optional)*—A graph of the percent passing versus log of particle size in mm.

14. Precision and Bias

14.1 *Precision*—Criteria for judging the acceptability of test results obtained by this test method using single sieve-set sieving on SP soil types are presented in 14.1.3 and 14.1.4. These estimates of precision are based on the results of the interlaboratory program conducted by the ASTM Reference Soils and Testing Program. In this program, the Moist Procedure, Method A (except two extra digits were recorded) and Single Sieve-Set Sieving procedures were used. The oven-dry mass of the specimen ranged between 97.56 g and 120.83 g, with an average value of 109.88 g and less than 30 % of the mass of the specimen was retained on any given sieve. In addition, some laboratories performed three replicate tests on the SP soil sample provided (triplicate test laboratories), while other laboratories performed a single test (single test laboratories). However, the data was processed twice to obtain a precision statement for both Method A and B. A description of the soil tested is given in 14.1.5. Testing precision may vary due to the specimen preparation procedure (moist, air-dried or oven-dried), the soil's gradation, and variations in the testing method used (Method A or B). If sample variability is assumed to be negligible, the analyses of the sieve data obtained in this program and others clearly indicate the following regarding sieving precision:

(a) Sieving precision cannot be accurately defined for an insignificant sieve (sieve in which 99 percent or more of the soil passes);

(b) Sieving precision is mainly a function of the amount of soil retained on a given sieve and the acceptable range in the size of the openings of a given sieve cloth;

(c) Sieving precision is also effected by sieve overloading, particle shape, and the slope of the gradation curve; and

(d) These items are interconnected in some manner, which has not been determined.

Additionally, judgement is necessary when applying these precision estimates to another soil.

14.1.1 *Precision Data Analysis*—Typically, precision statements include one or two variables per test, therefore, statements are presented in tabular format. However, in a sieve analysis, there are multiple variables (that is, a result for each sieve size) per test, therefore, it was determined that a non-tabular format would be appropriate.

14.1.1.1 As covered in Practices E177 and E691 and for most test methods, precision statements consist of two main components for each set of test results: Single-Operator Results (Within-Laboratory Repeatability) and Interlaboratory Results (Between-Laboratory Reproducibility). In addition, repeatability and reproducibility are composed of three key variables, the average value, the standard deviation (s) and the acceptable range of two results ($d2s$ or 95 % limit). The $d2s$ or 95 % limit is calculated as $1.960\times\sqrt{2}\times s$, as defined by Practice E177.

14.1.1.2 Based on the above, equations were developed to determine the repeatability and reproducibility standard deviation (s_r and s_R, respectively) as a function of the average percent retained on a given sieve ($avgPR_N$) for each set of test results (Method A and B). All values of $avgPR_N$ were less than 30 %. The equations developed are based on the upper bound (a straight line on which or below which all of the data points fall) of s_r or s_R versus $avgPR_N$ relationship, except if an unusually high outlier was noted. Then, using the appropriate s_r or s_R value, the repeatability limit (r) and reproducibility limit (R) can be determined, that is the acceptable range of two results or the $d2s$ or 95 % limit.

14.1.2 *Calculation of Precision*—To compare two test results using single sieve-set sieving and either Method A or B, use the following sequence to determine either the repeatability and reproducibility limit for each *Nth* sieve size of interest.

14.1.2.1 For both reported test results, determine the percent retained on a given *Nth* sieve (PR_N) which is a significant sieve (that is one in which less than 99 % passes or more than 1 % cumulative mass is retained). This PR_N is equal to the percent passing in the previous sieve (PP_{N-1}) less the percent passing for the given *Nth* sieve (PP_N). In this calculation, use the appropriate rounded PP_N value, for Method A to nearest 1 % and for Method B to nearest 0.1 %. This calculation is shown as follows:

$$PR_N = PP_{N-1} - PP_N \tag{16}$$

where:

PR_N = percent retained on *Nth* sieve, using single sieve-set sieving, %,

PP_{N-1} = percent passing the sieve previous to the *Nth* sieve, for Method A to nearest whole % and Method B to nearest 0.1 %, and

PP_N = percent passing the *Nth* sieve, for Method A to nearest whole % and Method B to nearest 0.1 %.

Then average the two values obtained for each *Nth* sieve size, without rounding, to determine the average percent retained for that *Nth* sieve size, $avgPR_N$. This $avgPR_N$ value shall not exceed 30 %. If it does, the precision shall not be determined for any sieve size within that test result (sieve analysis).

14.1.2.2 Use this $avgPR_N$ value and the appropriate precision equation in 14.1.3 or 14.1.4 to determine the repeatability standard deviation (s_r) or reproducibility standard deviation (s_R). Then, multiply this result by 1.960×√2 (or 2.772) and round the result as appropriate, for Method A to nearest 1 % and Method B to nearest 0.1 %. This value is either the Repeatability Limit (*r*) or the Reproducibility Limit (*R*), depending on the s_r or s_R equation used.

14.1.2.3 Determine the absolute (positive) difference between the two PR_N test values (PR_N) and compare it to the appropriate limit, *r* or *R* to see if that difference is acceptable; that is, PR_N is equal to or less than the appropriate *r* or *R* value. For significant sieves only, repeat this process for each pair of results. If there is a non-acceptable value, then both sets of test results shall be checked for any calculation and rounding errors and all sieves involved shall be checked for apparent deviations, for example, weaving defects, creases, wrinkles, foreign matter in the cloth, as covered in Specification E11, Test Method One. If other comparisons of test results continue to obtain non-acceptable values, then the determination of the size distribution of wire cloth openings shall be determined for all sieves involved, in accordance with Specification E11, Test Method Three. A set of example calculations is given in Appendix X2.

14.1.2.4 *Acceptance Criteria*—Duplicate test results (sieve analyses) are considered valid if no more than one sieve size has a non-acceptable value, as determined in 14.1.2.3. If a nonacceptable value is obtained for more than one sieve size, then one or both of the sets of test results (sieve analyses) are non-acceptable.

14.1.3 *Triplicate Test Precision Data (TTPD)*—The precision equations given below are based upon three replicate tests performed by each triplicate test laboratory on samples of an SP-type soil and upon information provided in 14.1 through 14.1.1.2. These equations are to be applied in accordance with 14.1.2. These equations apply specifically to the soil that was tested in the interlaboratory testing program.

14.1.3.1 *TTPD-Method A Repeatability*—This repeatability standard deviation for a given *Nth* sieve size ($As_{r,N}$) is equal to 0 % for $avgPR_N$ values equal to or less than 2 %. For $avgPR_N$ values greater than 2 %, calculate $As_{r,N}$ in % using the following equation:

$$As_{r,N} = 0.022 \times avgPR_N + 0.21 \tag{17}$$

14.1.3.2 *TTPD-Method A Reproducibility*—This reproducibility standard deviation for a given *Nth* sieve size ($As_{R,N}$ in %) is calculated using the following equation:

$$As_{R,N} = 0.073 \times avgPR_N + 0.43 \tag{18}$$

14.1.3.3 *TTPD-Method B Repeatability*—This repeatability standard deviation for a given *Nth* sieve size ($Bs_{r,N}$) is equal to the larger of 0.02 % or that using the following equation:

$$Bs_{r,N} = 0.0197 \times avgPR_N + 0.0055 \tag{19}$$

14.1.3.4 *TTPD-Method B Reproducibility*—This reproducibility standard deviation for a given *Nth* sieve size ($Bs_{R,N}$) is equal to the larger of 0.28 % or that using the following equation:

$$Bs_{R,N} = 0.0821 \times avgPR_N + 0.0110 \tag{20}$$

14.1.4 *Single Test Precision Data (STPD)*—In the ASTM Reference Soils and Testing Program, many of the laboratories performed only a single test. This is common practice in the design and construction industry. The equations given below are based upon the first test result from the triplicate test laboratories and the single test result from the other laboratories on samples of an SP-type soil and upon information provided in 14.1 through 14.1.1.2. These equations are to be applied in accordance with 14.1.2. The equations presented apply specifically to the soil that was tested in the interlaboratory testing program.

14.1.4.1 *STPD-Method A Reproducibility*—This reproducibility standard deviation for a given *Nth* sieve size ($As_{R,N}$ in %) is calculated using the following equation:

$$As_{R,N} = 0.038 \times avgPR_N + 0.65 \tag{21}$$

14.1.4.2 *STPD-Method B Reproducibility*—This reproducibility standard deviation for a given *Nth* sieve size ($Bs_{R,N}$) is equal to the larger of 0.382 % or that using the following equation:

$$Bs_{R,N} = 0.0462 \times avgPR_N + 0.357 \tag{22}$$

14.1.5 *Soil Type*—Based on the interlaboratory results, the soil used in the program is described below in accordance with Practice D2487. In addition, the local name of the soil is given: SP—Poorly graded sand, SP, 20 % coarse sand, 48 % medium sand, 30 % fine sand, 2 % fines, yellowish brown. Local name—Frederick sand.

14.1.6 *Discussion on Precision:*

14.1.6.1 The *TTPD* presents a rigorous interpretation of triplicate test data in accordance with Practice E691 from pre-qualified laboratories. *STPD* is derived from test data that would represent common practice.

14.1.6.2 It is quite possible that precision data presented for Method B is not as precise as it should be since a larger specimen should have been tested.

14.1.6.3 The precision data presented cannot be accurately applied to coarse-grained soils containing gravel size particles where more than 1 % gravel is contained in the sample/specimen. This statement is based on the precision data presented in Test Method C136, which demonstrated that the sieving precision decreases substantially when gravel specimens are tested versus sand specimens.

14.2 *Bias*—There is no accepted reference value for this test method, therefore, bias cannot be determined.

15. Keywords

15.1 gradation; grain size; particle size; particle-size distribution; sieve analysis; sieving

ANNEXES

(Mandatory Information)

A1. SYMBOLS

$1^{st}CSCF$ = 1^{st} composite sieving correction factor, which is equal to the percent passing the designated separating sieve size in the 1^{st} coarser sieve set while sieving the coarser portion of the specimen, %

$FP,CSCF$ = 1^{st} finer portion's composite sieving correction factor, which is equal to the finer portion's percent passing the last/bottom sieve in 2^{nd} coarser sieve set, %

$1^{st}FP,PP_N$ = 1^{st} finer portion's percent passing the *Nth* sieve in the 2^{nd} coarser sieve set while sieving the coarser portion of the 1^{st} subspecimen, %

$2^{nd}CP,FCMR_N$ = 2^{nd} coarser portion's fractional cumulative mass retained on *Nth* sieve in the 2^{nd} coarser sieve set, g or kg

$2^{nd}CP,FPP_N$ = 2^{nd} coarser portion's fractional percent passing the *Nth* sieve in the 2^{nd} coarser sieve set, decimal (not in %), or in %

$2^{nd}CP,FPR_{first}$ = 1^{st} fractional percent retained on the first sieve (sieve size equal to the designated separating sieve) in the 2^{nd} coarser sieve set while sieving the coarser portion of the 1^{st} subspecimen, %

$2^{nd}CP,M_d$ = dry mass of the 2^{nd} coarser portion, g or kg

$2^{nd}CP,MR_{pan}$ = dry mass retained in the pan after dry sieving the coarser portion, g or kg

$2^{nd}CP,PP_N$ = specimen's percent passing the *Nth* sieve in the 2^{nd} coarser sieve set while sieving the coarser portion of the 1^{st} subspecimen, %

$2^{nd}CP_L$ = percent of the 2^{nd}coarser portion lost during washing and dry sieving, %

$2^{nd}CP_w,M_d$ = dry mass of the 2^{nd} coarser portion after washing, g or kg

$2^{nd}CSCF$ = 2^{nd} composite sieving correction factor, which is equal to the percent passing the 2^{nd} designated separating sieve size in the 2^{nd} coarser sieve set while sieving the coarser portion of the 1^{st} subspecimen, %

$2^{nd}SubS,FCMR_{first}$ = 2^{nd} fractional cumulative mass retained on the first sieve in the finer sieve set while sieving the 2^{nd} subspecimen, g or kg (This mass is actually the mass retained since there is not any sieve above it.)

$2^{nd}SubS,FCMR_N$ = 2^{nd} subspecimen's fractional cumulative mass retained on the *Nth* sieve in the finer sieve set, g or kg

$2^{nd}SubS,FPP_N$ = 2^{nd} subspecimen's fractional percent passing the *Nth*th sieve in the finer sieve set, decimal (not in %) or in %

$2^{nd}SubS,FPR_{first}$ = 2^{nd} fractional percent retained on the first sieve (sieve size equal to the 2^{nd} designated separating sieve) in the finer sieve set while sieving the 2^{nd} subspecimen, %

$2^{nd}SubS,M_d$ = dry mass of the 2^{nd} subspecimen, g or kg

$2^{nd}SubS,PP_N$ = specimen's percent passing the *Nth* sieve in the finer sieve set while sieving the 2^{nd} subspecimen, %

AASHTO = American Association of State Highway and Transportation Officials

AMRL = AASHTO Materials Reference Laboratory

$As_{r,N}$ = Method A repeatability standard deviation for a given *Nth* sieve

$As_{R,N}$ = Method A reproducibility standard deviation for a given *Nth* sieve

$avgPR_N$ = average of two percent retained values on the *Nth* sieve between two laboratories or within laboratory

$Bs_{r,N}$ = Method B repeatability standard deviation for a given *Nth* sieve

$Bs_{R,N}$ = Method B reproducibility standard deviation for a given *Nth* sieve

CMR_N = cumulative mass retained on the th sieve; that is, the mass of material retained on the *Nth* sieve and those above it, g or kg

CMR_{N-1} = cumulative mass retained on the sieve above the *Nth* sieve, g or kg

CP,CMR_N = coarser portion's cumulative mass retained on the *Nth* sieve in the coarser sieve set, g or kg

CP,M_d = dry mass of the coarser portion, g or kg

CP,MR_{pan} = dry mass retained in the pan after dry sieving the coarser portion, g or kg

CP,PP_N = specimen's percent passing the *Nth* sieve in the coarser sieve set while sieving the coarser portion of the specimen, %

CP_L = percent of the coarser portion lost during washing and dry sieving, %
CP_w,M_d = dry mass of the coarser portion after washing, g or kg
$CSCF$ = composite sieving correction factor
$d2s$ = acceptable range of two results (or 95 % limit) calculated as $1.960\times\sqrt{2}\times s$, as defined by Practice E177
FP,M_m = moist or air-dried mass of the finer portion, g or kg
FP,PP_N = finer portion's percent passing the *Nth* sieve, %
MR_N = mass retained on the *Nth* sieve, g or kg
PP = percent passing, %
PP_N = percent passing the *Nth* sieve, %
PR = percent retained, %
s = standard deviation, units of calculation
S,M_d = dry mass of the specimen, g or kg
s_r = repeatability (within laboratory) standard deviation
s_R = reproducibility (between laboratories) standard deviation
$STPD$ = single test precision data
$SubS,FCMR_{first}$ = fractional cumulative mass retained on the first sieve in the 2nd coarser sieve set, g or kg (This mass is actually the mass retained since there is not any sieve above it.)
$SubS,FCMR_{first}$ = fractional cumulative mass retained on the first sieve in the finer sieve set, g or kg (This mass is actually the mass retained since there is not any sieve above it.)
$SubS,FCMR_N$ = subspecimen's fractional cumulative mass retained on the *Nth* sieve in the finer sieve set, g or kg
$SubS,FCPR_{first}$ = fractional cumulative percent retained on the first sieve (sieve size equal to the designated separating sieve) in the finer sieve set, %
$SubS,FPP_N$ = subspecimen's fractional percent passing the *Nth* sieve in the finer sieve set, decimal (not in %) or in %
$SubS,M_d$ = dry mass of the subspecimen, g or kg
$SubS,PP_N$ = specimen's percent passing the *Nth* sieve in the finer sieve set, %
$TTPD$ = triplicate test precision data
w_{fp} = water content of the finer portion, %
ΔPP_N = absolute (positive) difference between two PR_N test values (within laboratory or between laboratories)

A2. SAMPLE TO SPECIMEN SPLITTING/REDUCTION METHODS

A2.1 *General*—It is possible that bulk samples, jar samples, or specimens from prior testing may be significantly larger than needed for a sieve analysis. To reduce these samples to an appropriate specimen size, several techniques are applicable. The type and sizes of particles contained within the sample will influence the specimen processing and selection. Practice C702 provides details of mechanical splitting, quartering and miniature stockpile sampling for aggregate. When testing soils, these methods are adapted based on soil type. The goal is to have the specimen accurately represent the sample. Loss of particles (finer sizes) and segregation of particles are the most common problems when obtaining a specimen and most frequently occur during low or no moisture situations. Likewise, it is difficult to obtain a representative specimen if the sample contains excess or free water.

A2.1.1 *Mechanical Splitting*—This method is used only on dry samples that contain little or no fines. If the sample appears to create dust during the splitting, the sample has lost fines and mechanical splitting should be limited. For all soils, the splitting method may be used a maximum of two times, see 10.4.4. The splitter or riffle box shall conform to 6.9. The sample is placed in a feeder pan and distributed evenly throughout the pan. Pour the sample from the pan, into the hopper/feed chute, open the gate, if applicable, and allow the specimen to feed into the two catch pans. This process can be repeated once.

A2.1.2 *Quartering*—This method can be used on moist samples (see Practice C702), however it is often difficult and requires effort to collect all the finer particles. The sample is placed on a clean nonporous smooth surface (floor or sheet) and is thoroughly mixed using shovels, scoops, or spoons as appropriate for the sample size. Then, mound the sample into a cone-type shape by placing each shovelful or scoop on top of the preceding material. Flatten the cone to form a disk. Using a straight edge, or knife, divide the disk into wedge-shaped quarters. Remove two opposing quarters. Remix the remaining two quarters. Repeat this process until the mass of the remaining two quarters is greater than the minimum mass requirement, but less than 1.5 times the minimum mass requirement. If the sample is in a dry state, then this process can be repeated only once.

A2.1.3 *Miniature Stockpile Sampling*—This method is only applicable for moist samples. The sample is placed on a clean nonporous smooth surface and is thoroughly mixed using shovels, scoops or spoons as appropriate for the sample size. Then, mound the sample into a cone-type shape by placing each shovel full or scoop on top of the preceding shovel full or scoop of material. If desired, flatten the cone to form a disk. Using a scoop, obtain material from at least five locations in the pile. Scoop until the mass of the specimen is greater than the minimum mass requirement. Do not attempt to take very small scoops in order to obtain an exact mass because this could skew the particle-size distribution. In some cases, when working with relatively small samples and materials finer than the ⅜-in. (9.5-mm) sieve, a single scoop should be adequate.

A2.2 *Sample Processing Recommendations Based on Soil Type*—Estimate the soil classification using D2488. Then, use the following recommendations in conjunction with those given in Sections 9 and 10.

A2.2.1 *Clean Gravel (GW, GP) and Clean Sand (SW, SP)*—The condition of this sample should be moist or dry (air or oven). Either moist or dry (air or dry) processing can be used, although moist processing is probably easier, especially for sandy soils. The sample will require composite sieving if there are gravel size particles, see 10.3. If sample splitting is necessary to obtain a specimen, the sample can be mechanically split (dry processing), quartered (moist or dry processing), or sampled from a miniature stockpile (moist processing), to obtain a specimen. Refer to 10.4.1 (moist), 10.4.2 (air dried) or 10.4.3 (oven dried) for additional guidance.

A2.2.2 *Gravel with Fines (GM, GC, GC-GM, GW-GM, GW-GC, GP-GM, GP-GC)*—These soil types are the most difficult to obtain a gradation. The difficulty increases with increasing plasticity of the fines. The sample/specimen *will* require composite sieving due to the gravel size particles, see 10.3. Some of the fines may adhere to the gravel particles. Moist processing can be difficult, but with dry processing, it is often impossible or impractical to obtain a representative specimen. If the fine material appears to be wetter than the plastic limit (Test Method D4318), air-dry the sample until it is not sticky, but is still moist. If sample reduction is necessary, the sample can be quartered or sampled from a miniature stockpile to obtain a specimen. Then, it can be processed over the designated separating sieve as described in 10.5.2.

A2.2.3 *Sand with Silt Fines (SW-SM, SP-SM, SM)*—These soils should be processed in a moist state, see 10.5.1. The sample may require composite sieving if there is a wide range of particle sizes. The fines will frequently segregate from the sand and care must be taken to obtain a representative specimen. Moist processing will reduce the probability of segregation of fines. If sample reduction to obtain a specimen is needed, the sample can be quartered, or sampled from a miniature stockpile to obtain a specimen. Then, if composite sieving is necessary, it can be processed over the designated separating sieve as described in 10.5.2

A2.2.4 *Sand with Clay and Silt Fines or Clay Fines (SW-SC, SP-SC, SC, SC-SM) and Clays (CL, CL-ML, CH)*—These soils are processed in a moist state. If the fine material appears to be wetter than the plastic limit (Test Method D4318), air-dry the sample until it is not sticky, but is still moist. Complete drying of these materials usually creates hard lumps that can be difficult to disperse or break apart, see 10.5.2. The sample may require composite sieving if there is gravel size particles, see 10.3. If sample reduction is needed, the sample can be quartered, or sampled from a miniature stockpile to obtain a specimen. Then, if composite sieving is necessary, it can be processed over the designated separating sieve as described in 10.5.2.

A2.2.5 *Silts with Sand or Gravel, or Both (ML, MH)*—These soils are processed in a moist state. If the fine material appears to be wetter than the plastic limit (Test Method D4318), air-dry the sample until it is not sticky, but is still moist. The material may contain large particles and therefore require composite sieving, see 10.3. If sample reduction is needed, the sample can be quartered, or sampled from a miniature stockpile to obtain a specimen. Then, if composite sieving is necessary, it can be processed over the designated separating sieve as described in 10.5.2.

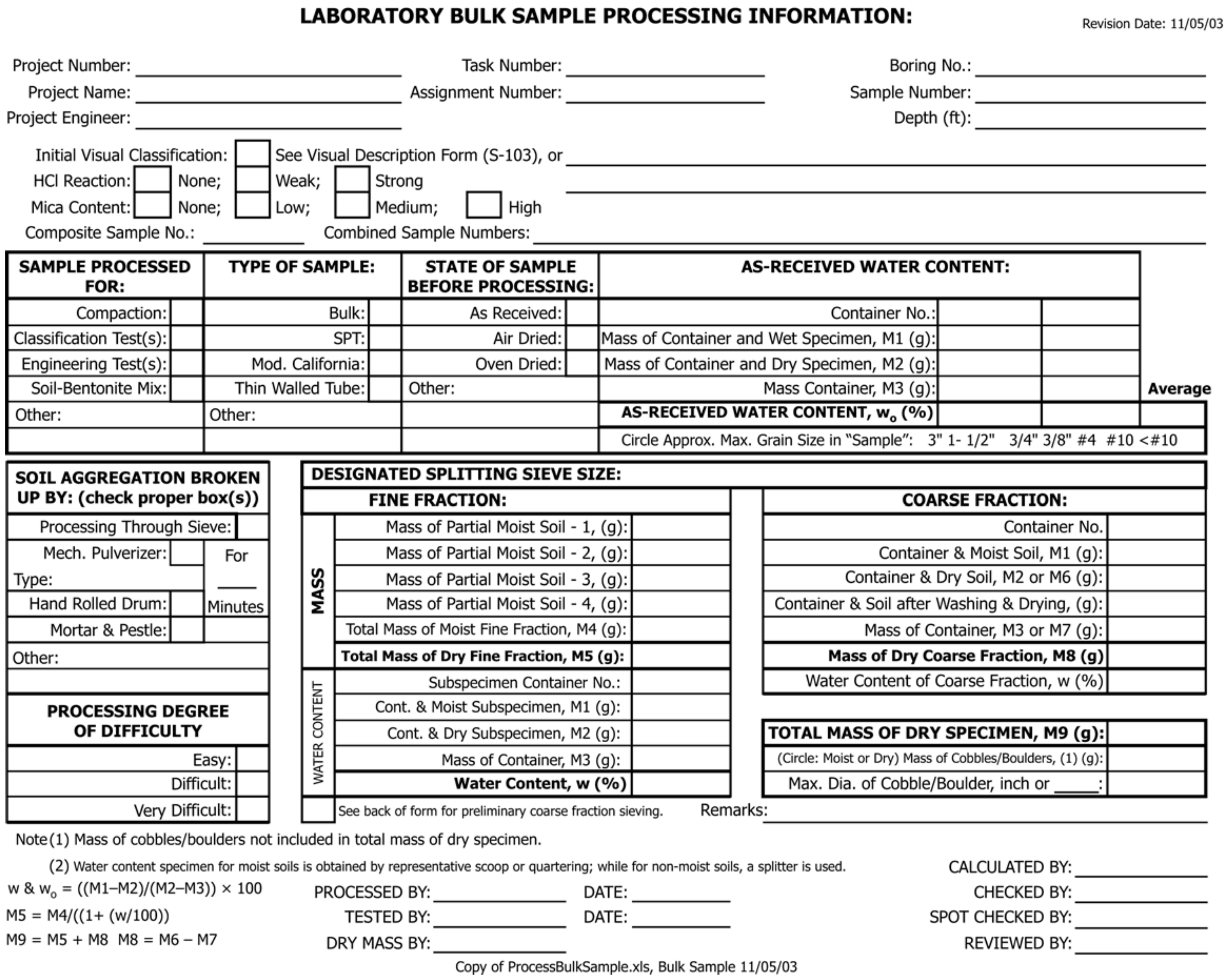
A2.2.6 *Organic Soils with Sand or Gravel, or Both (OL, OH)*—The organic soils are processed moist. If the material appears to be wetter than the plastic limit (Test Method D4318), air-dry the sample until it is not sticky, but is still moist. The material may contain large particles and therefore require composite sieving. Some of the organic material may easily break apart during processing. If sample reduction is needed, the sample can be quartered, or sampled from a miniature stockpile to obtain a specimen. Then, if composite sieving is necessary, it can be processed over the designated separating sieve as described in 10.5.2.

APPENDIXES

(Nonmandatory Information)

X1. EXAMPLE TEST DATA SHEETS/FORMS

X1.1 *General*—Two example data sheets are presented. Fig. X1.1 presents a data sheet that may be used in processing bulk samples in which a sieve-analysis specimen, or other testing, or both is needed. Fig. X1.2 presents a data sheet that may be used to record the sieve analysis data.



LABORATORY BULK SAMPLE PROCESSING INFORMATION:

Revision Date: 11/05/03

Project Number: ______________ Task Number: ______________ Boring No.: ______________

Project Name: ______________ Assignment Number: ______________ Sample Number: ______________

Project Engineer: ______________ Depth (ft): ______________

Initial Visual Classification: ☐ See Visual Description Form (S-103), or ______________

HCl Reaction: ☐ None; ☐ Weak; ☐ Strong

Mica Content: ☐ None; ☐ Low; ☐ Medium; ☐ High

Composite Sample No.: ________ Combined Sample Numbers: ______________

SAMPLE PROCESSED FOR:		TYPE OF SAMPLE:		STATE OF SAMPLE BEFORE PROCESSING:		AS-RECEIVED WATER CONTENT:			
Compaction:		Bulk:		As Received:		Container No.:			
Classification Test(s):		SPT:		Air Dried:		Mass of Container and Wet Specimen, M1 (g):			
Engineering Test(s):		Mod. California:		Oven Dried:		Mass of Container and Dry Specimen, M2 (g):			
Soil-Bentonite Mix:		Thin Walled Tube:		Other:		Mass Container, M3 (g):			**Average**
Other:		Other:				**AS-RECEIVED WATER CONTENT, w_o (%)**			
						Circle Approx. Max. Grain Size in "Sample": 3" 1- 1/2" 3/4" 3/8" #4 #10 <#10			

SOIL AGGREGATION BROKEN UP BY: (check proper box(s))		
Processing Through Sieve:		
Mech. Pulverizer:		For ____ Minutes
Type:		
Hand Rolled Drum:		
Mortar & Pestle:		
Other:		

PROCESSING DEGREE OF DIFFICULTY	
Easy:	
Difficult:	
Very Difficult:	

DESIGNATED SPLITTING SIEVE SIZE:

	FINE FRACTION:	
MASS	Mass of Partial Moist Soil - 1, (g):	
	Mass of Partial Moist Soil - 2, (g):	
	Mass of Partial Moist Soil - 3, (g):	
	Mass of Partial Moist Soil - 4, (g):	
	Total Mass of Moist Fine Fraction, M4 (g):	
	Total Mass of Dry Fine Fraction, M5 (g):	
WATER CONTENT	Subspecimen Container No.:	
	Cont. & Moist Subspecimen, M1 (g):	
	Cont. & Dry Subspecimen, M2 (g):	
	Mass of Container, M3 (g):	
	Water Content, w (%)	
☐	See back of form for preliminary coarse fraction sieving.	

COARSE FRACTION:	
Container No.	
Container & Moist Soil, M1 (g):	
Container & Dry Soil, M2 or M6 (g):	
Container & Soil after Washing & Drying, (g):	
Mass of Container, M3 or M7 (g):	
Mass of Dry Coarse Fraction, M8 (g)	
Water Content of Coarse Fraction, w (%)	

TOTAL MASS OF DRY SPECIMEN, M9 (g):	
(Circle: Moist or Dry) Mass of Cobbles/Boulders, (1) (g):	
Max. Dia. of Cobble/Boulder, inch or _____:	

Remarks: ______________

Note (1) Mass of cobbles/boulders not included in total mass of dry specimen.

(2) Water content specimen for moist soils is obtained by representative scoop or quartering; while for non-moist soils, a splitter is used.

w & w_o = ((M1–M2)/(M2–M3)) × 100

M5 = M4/((1+ (w/100))

M9 = M5 + M8 M8 = M6 – M7

PROCESSED BY: ______________ DATE: __________

TESTED BY: ______________ DATE: __________

DRY MASS BY: ______________

CALCULATED BY: ______________

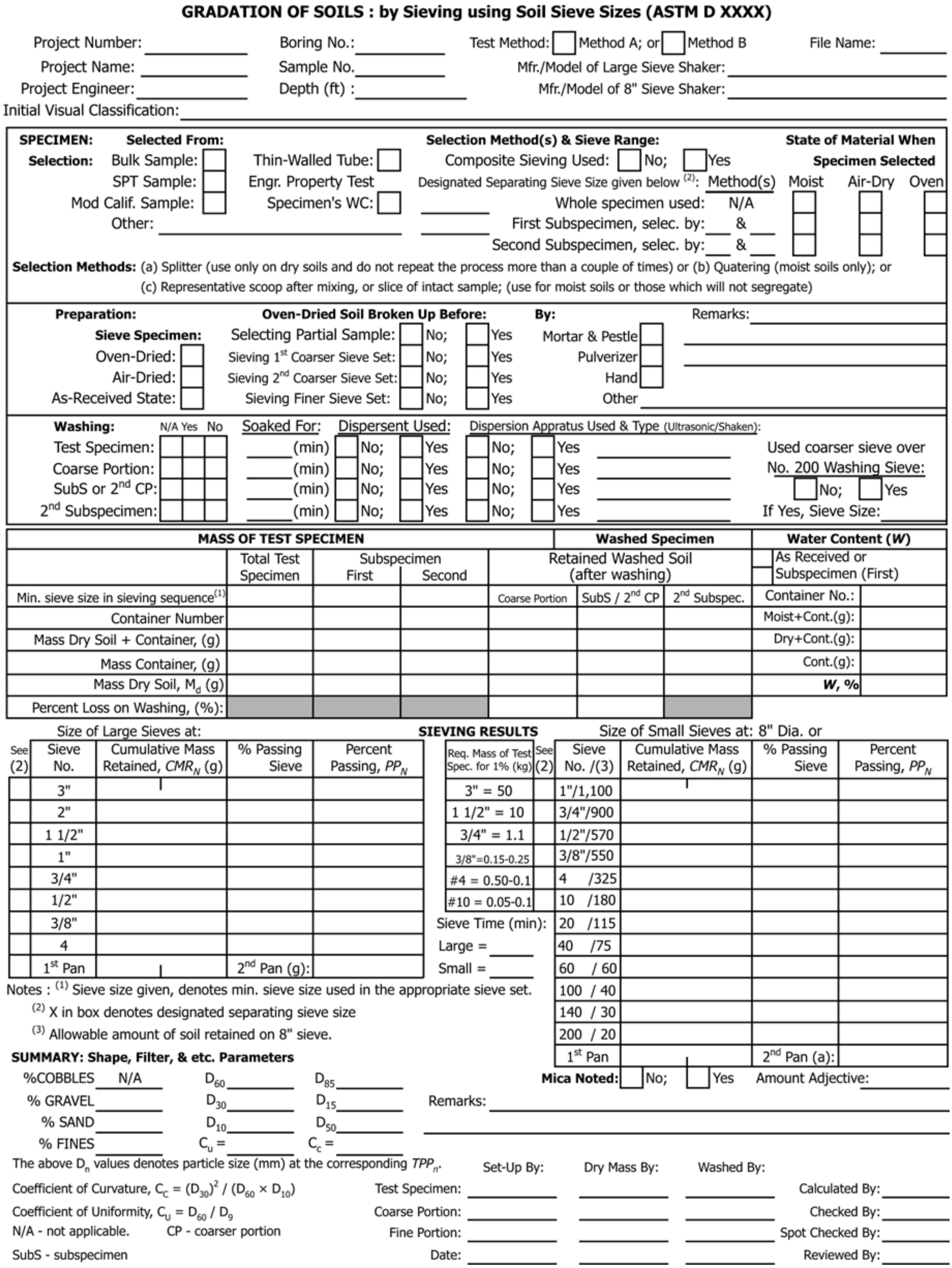
CHECKED BY: ______________

SPOT CHECKED BY: ______________

REVIEWED BY: ______________

Copy of ProcessBulkSample.xls, Bulk Sample 11/05/03

FIG. X1.1 Example Bag Sample Processing Data Sheet



GRADATION OF SOILS : by Sieving using Soil Sieve Sizes (ASTM D XXXX)

Project Number: ____ Boring No.: ____ Test Method: ☐ Method A; or ☐ Method B File Name: ____
Project Name: ____ Sample No. ____ Mfr./Model of Large Sieve Shaker: ____
Project Engineer: ____ Depth (ft) : ____ Mfr./Model of 8" Sieve Shaker: ____
Initial Visual Classification: ____

SPECIMEN: Selected From: **Selection Method(s) & Sieve Range:** **State of Material When**
Selection: Bulk Sample: ☐ Thin-Walled Tube: ☐ Composite Sieving Used: ☐ No; ☐ Yes **Specimen Selected**
SPT Sample: ☐ Engr. Property Test Designated Separating Sieve Size given below $^{(2)}$: Method(s) Moist Air-Dry Oven
Mod Calif. Sample: ☐ Specimen's WC: ☐ ____ Whole specimen used: N/A ☐ ☐ ☐
Other: ____ ____ First Subspecimen, selec. by: ___ & ___ ☐ ☐ ☐
Second Subspecimen, selec. by: ___ & ___ ☐ ☐ ☐

Selection Methods: (a) Splitter (use only on dry soils and do not repeat the process more than a couple of times) or (b) Quatering (moist soils only); or (c) Representative scoop after mixing, or slice of intact sample; (use for moist soils or those which will not segregate)

Preparation: **Oven-Dried Soil Broken Up Before:** **By:** Remarks: ____
Sieve Specimen: Selecting Partial Sample: ☐ No; ☐ Yes Mortar & Pestle ☐ ____
Oven-Dried: ☐ Sieving 1st Coarser Sieve Set: ☐ No; ☐ Yes Pulverizer ☐ ____
Air-Dried: ☐ Sieving 2nd Coarser Sieve Set: ☐ No; ☐ Yes Hand ☐
As-Received State: ☐ Sieving Finer Sieve Set: ☐ No; ☐ Yes Other ____

Washing:	N/A	Yes	No	Soaked For:	Dispersent Used:		Dispersion Apprratus Used & Type (Ultrasonic/Shaken):			
Test Specimen:	☐	☐	☐	____(min)	☐ No;	☐ Yes	☐ No;	☐ Yes	____	Used coarser sieve over
Coarse Portion:	☐	☐	☐	____(min)	☐ No;	☐ Yes	☐ No;	☐ Yes	____	No. 200 Washing Sieve:
SubS or 2nd CP:	☐	☐	☐	____(min)	☐ No;	☐ Yes	☐ No;	☐ Yes	____	☐ No; ☐ Yes
2nd Subspecimen:	☐	☐	☐	____(min)	☐ No;	☐ Yes	☐ No;	☐ Yes	____	If Yes, Sieve Size: ____

MASS OF TEST SPECIMEN				**Washed Specimen**			**Water Content (*W*)**	
	Total Test Specimen	Subspecimen First	Subspecimen Second	Retained Washed Soil (after washing)			☐ As Received or ☐ Subspecimen (First)	
Min. sieve size in sieving sequence$^{(1)}$				Coarse Portion	SubS / 2nd CP	2nd Subspec.	Container No.:	
Container Number							Moist+Cont.(g):	
Mass Dry Soil + Container, (g)							Dry+Cont.(g):	
Mass Container, (g)							Cont.(g):	
Mass Dry Soil, M_d (g)							***W*, %**	
Percent Loss on Washing, (%):	▨	▨	▨			▨		

Size of Large Sieves at: **SIEVING RESULTS** Size of Small Sieves at: 8" Dia. or

See (2)	Sieve No.	Cumulative Mass Retained, CMR_N (g)	% Passing Sieve	Percent Passing, PP_N
	3"			
	2"			
	1 1/2"			
	1"			
	3/4"			
	1/2"			
	3/8"			
	4			
	1st Pan		2nd Pan (g):	

Req. Mass of Test Spec. for 1% (kg)	See (2)	Sieve No. /(3)	Cumulative Mass Retained, CMR_N (g)	% Passing Sieve	Percent Passing, PP_N
3" = 50		1"/1,100			
1 1/2" = 10		3/4"/900			
3/4" = 1.1		1/2"/570			
3/8"=0.15-0.25		3/8"/550			
#4 = 0.50-0.1		4 /325			
#10 = 0.05-0.1		10 /180			
Sieve Time (min):		20 /115			
Large = ____		40 /75			
Small = ____		60 / 60			
		100 / 40			
		140 / 30			
		200 / 20			
		1st Pan		2nd Pan (a):	

Notes : $^{(1)}$ Sieve size given, denotes min. sieve size used in the appropriate sieve set.
$^{(2)}$ X in box denotes designated separating sieve size
$^{(3)}$ Allowable amount of soil retained on 8" sieve.

Mica Noted: ☐ No; ☐ Yes Amount Adjective: ____

SUMMARY: Shape, Filter, & etc. Parameters

%COBBLES N/A D_{60} ____ D_{85} ____
% GRAVEL ____ D_{30} ____ D_{15} ____ Remarks: ____
% SAND ____ D_{10} ____ D_{50} ____
% FINES ____ C_u = ____ C_c = ____

The above D_n values denotes particle size (mm) at the corresponding TPP_n.
Coefficient of Curvature, $C_C = (D_{30})^2 / (D_{60} \times D_{10})$
Coefficient of Uniformity, $C_U = D_{60} / D_9$
N/A - not applicable. CP - coarser portion
SubS - subspecimen

	Set-Up By:	Dry Mass By:	Washed By:	
Test Specimen:	____	____	____	Calculated By: ____
Coarse Portion:	____	____	____	Checked By: ____
Fine Portion:	____	____	____	Spot Checked By: ____
Date:	____	____	____	Reviewed By: ____

FIG. X1.2 Example Gradation of Soils Data Sheet

X2. PRECISION: EXAMPLE CALCULATIONS

X2.1 *General*—Two sets of example calculations are provided for comparing test results (sieve analyses) obtained within and between laboratories. The first example, Fig. X2.1, presents results for sieve analyses using Method A (data to the nearest whole percentage) and based upon the triplicate test precision data. The second example, Fig. X2.2, presents results for sieve analyses using Method B (data to the nearest 0.1 %) and based upon the triplicate and single test precision data.

Method A - Example Calculations for Within Laboratory Precision (Repeatability)
Based Upon Triplicate Test Precision Data

Equation for Repeatability Standard Deviation: $As_{r,n} = 0.022 \times avgPR_n + 0.21$ or 0 if $avgPR_n$ is equal to or less than 2%

Alternate Sieve Size	Lab 14 Test Results Percent Passing, PP_n Trial Number		Percent Retained, PR_n Trial Number		Average Percent Retained, $avgPR_n$	Method A - Repeatability Standard Deviation, $As_{r,n}$	Repeatability Limit, r (1)	Absolute Difference Between PR_n Values, ΔPR_n	ΔPR_n minus r	Acceptability: ΔPR_n =or< r Yes or No
	1	2	1	2						
No.4	100	100	0	0	N/A	N/A	N/A	N/A	N/A	N/A
10	80	81	20	19	19.5	0.639	2	1	–1	Yes
20	59	61	21	20	20.5	0.661	2	1	–1	Yes
40	33	33	26	28	27	0.804	2	2	0	Yes
60	10	11	23	22	22.5	0.705	2	1	–1	Yes
100	4	4	6	7	6.5	0.353	1	1	0	Yes
140	3	3	1	1	1	0	0	0	0	Yes
200	2	2	1	1	1	0	0	0	0	Yes
									Precision Acceptance:	Valid Duplicates

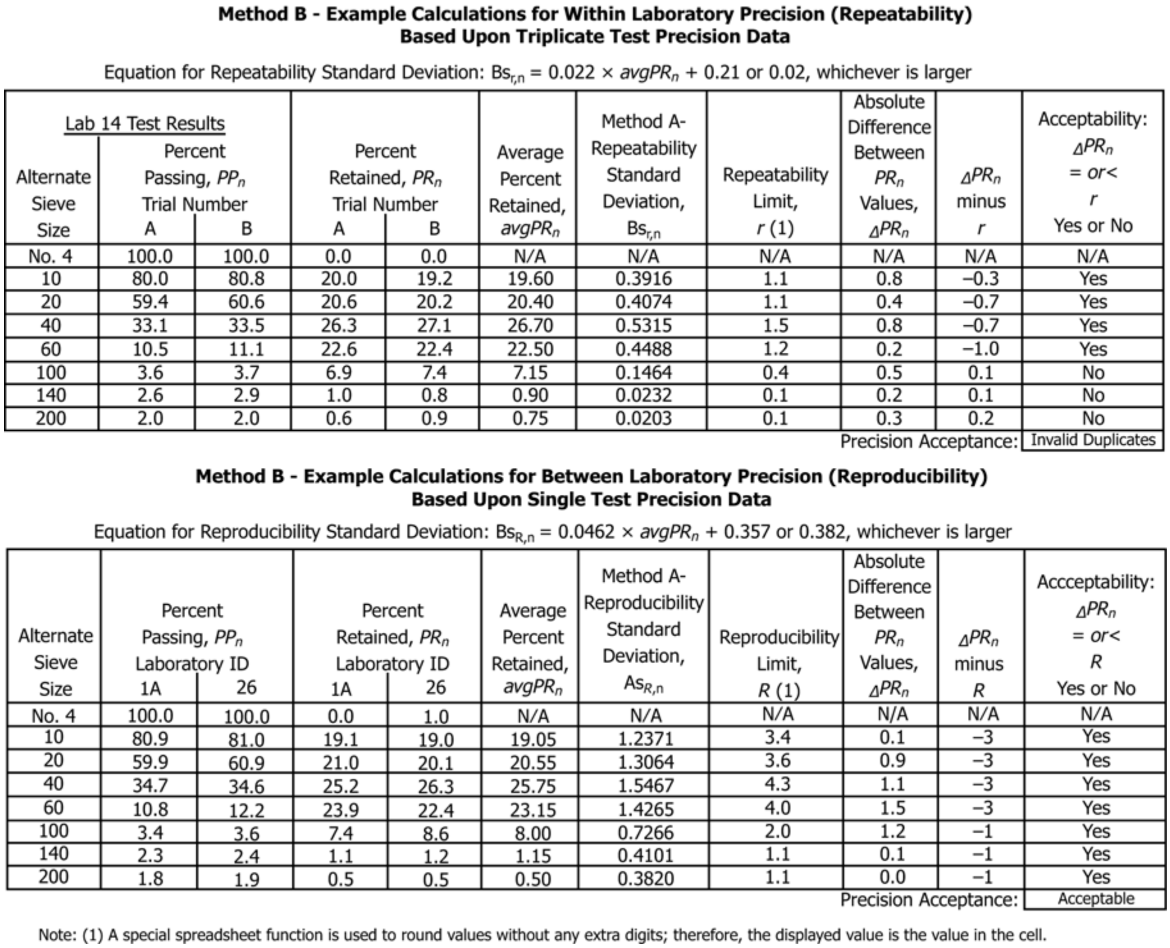
Method A - Example Calculations for Between Laboratory Precision (Reproducibility)
Based Upon Triplicate Test Precision Data

Equation for Reproducibility Standard Deviation: $As_{r,n} = 0.073 \times avgPR_n + 0.43$

Alternate Sieve Size	Percent Passing, PP_n Laboratory ID		Percent Retained, PR_n Laboratory ID		Average Percent Retained, $avgPR_n$	Method A - Reproducibility Standard Deviation, $As_{R,n}$	Reproducibility Limit, R (1)	Absolute Difference Between PR_n Values, ΔPR_n	ΔPR_n minus R	Acceptability: ΔPR_n =or< R Yes or No
	1A	23A (2)	1A	23A						
No.4	100	100	0	1	N/A	N/A	N/A	N/A	N/A	N/A
10	81	81	19	19	19	1.817	5	0	–5	Yes
20	60	58	21	23	22	2.036	6	2	–4	Yes
40	35	27	25	31	28	2.474	7	6	–1	Yes
60	11	9	24	18	21	1.963	5	6	1	No
100	3	3	8	6	7	0.941	3	2	–1	Yes
140	2	2	1	1	1	0.503	1	0	–1	Yes
200	2	0	0	2	1	0.503	1	2	1	No
									Precision Acceptance:	Non-acceptable

Note: (1) A special spreadsheet function is used to round values without any extra digits; therefore, the displayed value is the value in the cell.
(2) Some data was adjusted to create non-acceptable data.

FIG. X2.1 Precision Example Calculations: Method A—Triplicate Test Precision Data



Method B - Example Calculations for Within Laboratory Precision (Repeatability)
Based Upon Triplicate Test Precision Data

Equation for Repeatability Standard Deviation: $Bs_{r,n}$ = 0.022 × $avgPR_n$ + 0.21 or 0.02, whichever is larger

Lab 14 Test Results Alternate Sieve Size	Percent Passing, PP_n Trial Number A	B	Percent Retained, PR_n Trial Number A	B	Average Percent Retained, $avgPR_n$	Method A-Repeatability Standard Deviation, $Bs_{r,n}$	Repeatability Limit, r (1)	Absolute Difference Between PR_n Values, ΔPR_n	ΔPR_n minus r	Acceptability: ΔPR_n = or< r Yes or No
No. 4	100.0	100.0	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A
10	80.0	80.8	20.0	19.2	19.60	0.3916	1.1	0.8	−0.3	Yes
20	59.4	60.6	20.6	20.2	20.40	0.4074	1.1	0.4	−0.7	Yes
40	33.1	33.5	26.3	27.1	26.70	0.5315	1.5	0.8	−0.7	Yes
60	10.5	11.1	22.6	22.4	22.50	0.4488	1.2	0.2	−1.0	Yes
100	3.6	3.7	6.9	7.4	7.15	0.1464	0.4	0.5	0.1	No
140	2.6	2.9	1.0	0.8	0.90	0.0232	0.1	0.2	0.1	No
200	2.0	2.0	0.6	0.9	0.75	0.0203	0.1	0.3	0.2	No
								Precision Acceptance:		Invalid Duplicates

Method B - Example Calculations for Between Laboratory Precision (Reproducibility)
Based Upon Single Test Precision Data

Equation for Reproducibility Standard Deviation: $Bs_{R,n}$ = 0.0462 × $avgPR_n$ + 0.357 or 0.382, whichever is larger

Alternate Sieve Size	Percent Passing, PP_n Laboratory ID 1A	26	Percent Retained, PR_n Laboratory ID 1A	26	Average Percent Retained, $avgPR_n$	Method A-Reproducibility Standard Deviation, $As_{R,n}$	Reproducibility Limit, R (1)	Absolute Difference Between PR_n Values, ΔPR_n	ΔPR_n minus R	Accceptability: ΔPR_n = or< R Yes or No
No. 4	100.0	100.0	0.0	1.0	N/A	N/A	N/A	N/A	N/A	N/A
10	80.9	81.0	19.1	19.0	19.05	1.2371	3.4	0.1	−3	Yes
20	59.9	60.9	21.0	20.1	20.55	1.3064	3.6	0.9	−3	Yes
40	34.7	34.6	25.2	26.3	25.75	1.5467	4.3	1.1	−3	Yes
60	10.8	12.2	23.9	22.4	23.15	1.4265	4.0	1.5	−3	Yes
100	3.4	3.6	7.4	8.6	8.00	0.7266	2.0	1.2	−1	Yes
140	2.3	2.4	1.1	1.2	1.15	0.4101	1.1	0.1	−1	Yes
200	1.8	1.9	0.5	0.5	0.50	0.3820	1.1	0.0	−1	Yes
								Precision Acceptance:		Acceptable

Note: (1) A special spreadsheet function is used to round values without any extra digits; therefore, the displayed value is the value in the cell.

FIG. X2.2 Precision Example Calculations: Method B—Triplicate and Single Test Precision Data

Designation: D7928 – 17

Standard Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis[1]

This standard is issued under the fixed designation D7928; 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 test method covers the quantitative determination of the distribution of particle sizes of the fine-grained portion of soils. The sedimentation or hydrometer method is used to determine the particle-size distribution (gradation) of the material that is finer than the No. 200 (75-µm) sieve and larger than about 0.2-µm. The test is performed on material passing the No. 10 (2.0-mm) or finer sieve and the results are presented as the mass percent finer versus the log of the particle diameter.

1.2 This method can be used to evaluate the fine-grained fraction of a soil with a wide range of particle sizes by combining the sedimentation results with a sieve analysis resulting in the complete gradation curve. The method can also be used when there are no coarse-grained particles or when the gradation of the coarse-grained material is not required or not needed.

NOTE 1—The significant digits recorded in this test method preclude obtaining the grain size distribution of materials that do not contain a significant amount of fines. For example, clean sands will not yield detectable amounts of silt and clay sized particles, and therefore should not be tested with this method. The minimum amount of fines in the sedimentation specimen is 15 g.

1.3 When combining the results of the sedimentation and sieve tests, the procedure for obtaining the material for the sedimentation analysis and calculations for combining the results will be provided by the more general test method, such as Test Methods D6913 (Note 2).

NOTE 2—Subcommittee D18.03 is currently developing a new test method "Test Method for Particle-Size Analysis of Soils Combining the Sieve and Sedimentation Techniques."

1.4 The terms "soil" and "material" are used interchangeably throughout the standard.

1.5 The sedimentation analysis is based on the concept that larger particles will fall through a fluid faster than smaller particles. Stokes' Law gives a governing equation used to determine the terminal velocity of a spherical particle falling through a stationary liquid. The terminal velocity is proportional to the square of the particle diameter. Therefore, particles are sorted by size in both time and position when settling in a container of liquid.

1.5.1 Stokes' Law has several assumptions which are: the particles are spherical and smooth; there is no interference between the particles; there is no difference between the current in the middle of the container and the sides; flow is laminar; and the particles have the same density. These assumptions are applied to soil particles of various shapes and sizes.

1.6 A hydrometer is used to measure the fluid density and determine the quantity of particles in suspension at a specific time and position. The density of the soil-water suspension depends upon the concentration and specific gravity of the soil particles and the amount of dispersant added. Each hydrometer measurement at an elapsed time is used to calculate the percentage of particles finer than the diameter given by Stokes' Law. The series of readings provide the distribution of material mass as a function of particle size.

1.7 This test method does not cover procurement of the sample or processing of the sample prior to obtaining the reduced sample in any detail. It is assumed that the sample is obtained using appropriate methods and is representative of site materials or conditions. It is also assumed that the sample has been processed such that the reduced sample accurately reflects the particle-size distribution (gradation) of this finer fraction of the material.

1.8 *Material Processing*—Material is tested in the moist or as-received state unless the material is received in an air-dried state. The moist preparation method shall be used to obtain a sedimentation test specimen from the reduced sample. Air-dried preparation is only allowed when the material is received in the air-dried state. The method to be used may be specified by the requesting authority; however, the moist preparation method shall be used for referee testing.

1.9 This test method is **not** applicable for the following soils:

1.9.1 Soils containing fibrous peat.

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[1] This test method is under the jurisdiction of ASTM Committee D18 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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1.9.2 Soils containing less than approximately 5 % of fine-grained material (Note 1).

1.9.3 Soils containing extraneous matter, such as organic solvents, oil, asphalt, wood fragments, or similar items (Note 3).

NOTE 3—If extraneous matter, such as wood, can be easily removed by hand, it is permissible to do so. However, there may be cases where the extraneous matter is being evaluated as part of the material and it should not be removed from the material.

1.9.4 Materials that contain cementitious components, such as cement, fly ash, lime, or other stabilization admixtures.

1.10 This test method may not produce consistent test results within and between laboratories for the following soils. To test these soils, this test method must be adapted and these adaptations documented.

1.10.1 Soils that flocculate during sedimentation. Such materials may need to be treated to reduce salinity or alter the pH of the suspension.

1.10.2 Friable soils in which processing changes the gradation of the soil. Typical examples of these soils are some residual soils, most weathered shales, and some weakly cemented soils.

1.10.3 Soils that will not readily disperse, such as glauconitic clays or some dried plastic clays.

1.11 Samples that are not soils, but are made up of particles may be tested using this method. The applicable sections above should be used in applying this standard.

1.12 *Units*—The values stated in SI units are to be regarded as standard. Except the sieve designations, they are identified using the "alternative" system in accordance with Practice E11, such as 3-in. and No. 200, instead of the "standard" of 75-mm and 75-µm, respectively. Reporting of test results in units other than SI shall not be regarded as non-conformance with this test method. The use of balances or scales recording pounds of mass (lbm) shall not be regarded as nonconformance with this standard.

1.13 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026, unless superseded by this test method.

1.13.1 The procedures used to specify how data are collected/recorded and calculated in the standard are regarded as the industry standard. In addition, they are representative of the significant digits that generally should be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of these test methods to consider significant digits used in analysis methods for engineering data.

1.14 *This standard does not purport to address all of the safety concerns, if any, 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.*

1.15 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids
D854 Test Methods for Specific Gravity of Soil Solids by Water Pycnometer
D1140 Test Methods for Determining the Amount of Material Finer than 75-µm (No. 200) Sieve in Soils by Washing
D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
D2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)
D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D4220/D4220M Practices for Preserving and Transporting Soil Samples
D4318 Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
D4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing
D6026 Practice for Using Significant Digits in Geotechnical Data
D6913 Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis
E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves
E100 Specification for ASTM Hydrometers
E126 Test Method for Inspection, Calibration, and Verification of ASTM Hydrometers

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of common technical terms used in this standard, refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *reduced sample, n*—the minus ⅜-in. (9.5-mm) sieve or finer material that has been separated from the sample and then worked to reduce the mass while still having sufficient quantity to meet the minimum mass requirements of Table 1.

3.2.2 *sample, n*—material collected without limitation on the total mass or size range of particles meeting the minimum mass requirements provided in Table 1.

3.2.3 *sedimentation sample, n*—the minus No. 10 (2.0-mm) or finer material that is separated from the reduced sample

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

TABLE 1 Minimum Dry Mass Requirements

Maximum Particle Size of Material (99% or more passing)		Minimum Dry Mass	Comments on separating and splitting requirements for sample reduction
Sieve Designation	Particle Size, mm		
6 in.	152.4	500 kg	Several separations
3 in.	76.2	70 kg	Several separations
1 in.	25.4	3 kg	At least one separation
¾ in.	19.1	1.3 kg	Most likely one separation
⅜ in.	9.5	165 g	Separation for sedimentation analysis
No. 10	2.0	50 g	Splitting only

using the separation sieve from which the sedimentation specimen and water content are obtained.

3.2.4 *sedimentation specimen, n*—the material obtained from the sedimentation sample having a maximum particle-size no greater than the No. 10 (2.0-mm) sieve to be used in the sedimentation test and in sufficient quantity to satisfy the minimum mass requirements of Table 1.

3.2.5 *separation sieve, n*—the No. 10 (2.0-mm) sieve or finer (Note 4) used to separate the reduced sample to obtain the material for the sedimentation sample.

NOTE 4—The methodology for using a sieve finer than the No. 10 (2.0 mm) is not defined in this standard. The methodology used to obtain a representative sample using a sieve finer than the No. 10 (2.0 mm) is not the same as obtaining the representative sample using the No. 10 (2.0 mm) sieve as presented in this standard. Additional effort or steps are necessary to make sure the material passing the finer sieve adequately represents the sample. Such additional effort or steps should be documented if using a sieve finer than the No. 10 (2.0 mm) sieve to obtain the sedimentation specimen.

4. Summary of Test Method

4.1 This test method is used to determine the particle-size distribution (gradation) of material finer than the No. 200 (75-µm) sieve as a percentage of the mass used in the sedimentation test.

4.2 When the source material contains particles larger than the ⅜-in. (9.5-mm) sieve, a reduced sample passing the ⅜-in. (9.5-mm) sieve shall be obtained using techniques presented in Test Methods D6913 or another standard. This reduced sample shall meet the minimum mass requirements in Table 1 for the ⅜-in. (9.5-mm) sieve. The material is processed using the moist (referee) preparation method unless the material is received in the air-dried state.

4.3 The entire reduced sample is separated using the separation sieve. The sedimentation sample is then split to obtain the appropriate mass for the sedimentation test specimen and a water content test specimen.

4.4 The sedimentation test specimen is mixed with a dispersing agent and test water. The slurry is allowed to condition and is then thoroughly mixed and placed in a cylinder with additional test water. Readings are taken with a hydrometer and thermometer over specific time intervals.

4.5 The mass of particles passing specified particle diameters are calculated and recorded. The results produce a tabulation of particle size versus percent passing that can be graphically presented as a gradation curve. The plot is typically expressed as percent passing/finer than the separation sieve size versus the log of the particle size in millimetres.

5. Significance and Use

5.1 Particle-size distribution (gradation) is a descriptive term referring to the proportions by dry mass of a soil distributed over specified particle-size ranges. The gradation curve generated using this method yields the amount of silt and clay size fractions present in the soil based on size definitions, not mineralogy or Atterberg limit data.

5.2 Determination of the clay size fraction, which is material finer than 2 µm, is used in combination with the Plasticity Index (Test Methods D4318) to compute the activity, which provides an indication of the mineralogy of the clay fraction.

5.3 The gradation of the silt and clay size fractions is an important factor in determining the susceptibility of fine-grained soils to frost action.

5.4 The gradation of a soil is an indicator of engineering properties. Hydraulic conductivity, compressibility, and shear strength are related to the gradation of the soil. However, engineering behavior is dependent upon many factors, such as effective stress, mineral type, structure, plasticity, and geological origin, and cannot be based solely upon gradation.

5.5 Some types of soil require special treatment in order to correctly determine the particle sizes. For example, chemical cementing agents can bond clay particles together and should be treated in an effort to remove the cementing agents when possible. Hydrogen peroxide and moderate heat can digest organics. Hydrochloric acid can remove carbonates by washing and Dithionite-Citrate-Bicarbonate extraction can be used to remove iron oxides. Leaching with test water can be used to reduce salt concentration. All of these treatments, however, add significant time and effort when performing the sedimentation test and are allowable but outside the scope of this test method.

5.6 The size limits of the sedimentation test are from about 100 µm to about 1 µm. The length of time required to obtain a stable initial reading on the hydrometer controls the upper range of results, and the test duration controls the lower range.

5.7 The shape and density of the grains are important to the results. Stokes' Law is assumed to be valid for spherical particles even though fine silt- and clay-sized particles are more likely to be plate-shaped and have greater mineral densities than larger particles.

NOTE 5—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *Hydrometer*—ASTM hydrometer type 151H or 152H. These hydrometers shall conform to the requirements in Specification E100. See Annex A1.

6.2 *Sedimentation Cylinder*—At least two glass cylinders essentially having a height of about 457 mm, an inside diameter between 55 and 64 mm, and a capacity of 1,000 mL. The cylinders shall have an indication mark at 1,000 ± 5 mL. One cylinder is used for the soil suspension and the other one can be used as the control cylinder or the wash cylinder. The control cylinder shall have the same amount of dispersant as the soil suspension cylinder. See Annex A1.

6.3 *Separation Sieve*—No. 10 (2-mm) or finer sieve used to separate the reduced sample. This sieve is subjected to rough operation and shall not be used for quantitative grain size analysis.

6.4 *Thermometric Device*—A thermometric device capable of measuring the temperature range within which the test is being performed readable to 0.5°C or better and having an accuracy of at least ±0.5°C. The thermometric device must be capable of being immersed in the suspension and reference solutions to a depth ranging between 25 and 80 mm. Full immersion, also known as complete or total immersion thermometers, shall not be used. The thermometric device shall be standardized by comparison to a nationally or internationally traceable thermometric device and shall include at least one temperature reading within the range of testing. The thermometric device shall be standardized at least once every twelve months. The same thermometric device shall be used for all measurements.

6.5 *Timing Device*—A clock, stopwatch, digital timer, or comparable device readable to one second or better.

6.6 *Balance*—Balances shall conform to the requirements of Specification D4753.

6.6.1 To determine the mass of the specimen, the balance shall have readability without estimation of 0.01 g. The capacity of this balance will need to exceed the mass of the container plus soil used to contain the soil suspension after the completion of the sedimentation test. In general, a balance with a minimum capacity of 1,800 g is sufficient.

6.7 *Drying Oven*—Vented, thermostatically controlled oven capable of maintaining a uniform temperature of 110 ± 5°C throughout the drying chamber. These requirements typically require the use of a forced-draft oven.

6.8 *Plate*—A clean, nonporous, smooth, solid surface that is large enough to pile and split about 500 g of material. The surface shall not be made of any type of paper product.

6.9 *Specimen-Mixing Container*—A 250-mL glass beaker or equivalent inert container with enough capacity to hold the specimen, the test water, and dispersant.

6.10 *Temperature Maintaining Device*—Unless otherwise specified by the requesting agency, the standard test temperature shall be in the range of 22 ± 5°C. In addition, the temperature of the soil suspension shall not vary more than ±2°C. Normally, this temperature maintenance is accomplished by performing the test in a room with a relatively constant temperature. If such a room is not available, the cylinders shall be placed in an automatically temperature controlled insulated chamber or water bath that maintains a temperature within the tolerance specified above.

6.11 *Soil Suspension Oven-Drying Container*—A container having smooth walls and capable of holding approximately 1.5-L of the soil suspension. This container shall have a tight fitting lid or fit into a desiccator, to prevent moisture gain during cooling of the oven-dried specimen.

6.12 *Dispersion Apparatus*—Use one of the following devices to disperse the specimen; however for referee testing, the stirring apparatus shall be used.

6.12.1 *Stirring Apparatus (Referee)*—A mechanically operated stirring device in which a suitably mounted electric motor turns a vertical shaft at a minimum speed of 10,000 rpm without load. The shaft shall be equipped with a replaceable stirring paddle made of metal, as shown in Fig. 1. The shaft shall be of such length that the stirring paddle will operate between 19.0-mm and 37.5-mm above the bottom of the dispersion cup (Note 6).

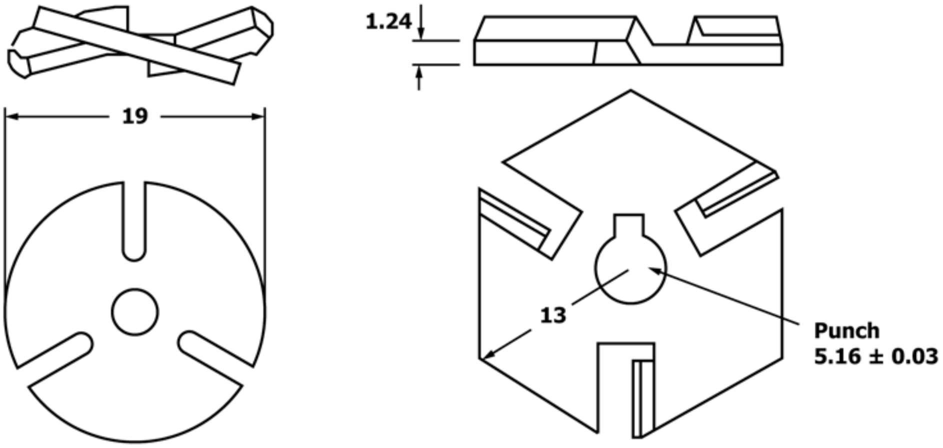
NOTE 6—The SI units presented are basically soft conversions of the inch-pound units; other rationalized SI units should be acceptable providing they meet the requirements established by the inch-pound apparatus.

6.12.1.1 *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. The cup shall contain two sets of three long baffle rods and two sets of three short baffle rods rigidly mounted to the interior sides of the cup. This cup is used with the stirring apparatus.

6.12.2 *Air Jet Dispersion Device (Optional)*—A tube type or other comparable device that uses compressed air to disperse the slurry (Note 7). The device requires an air source capable of providing up to 0.0024 m^3/s of air to operate the device, such that pressures of 69 and 172 kPa can be achieved. The device shall be fitted with a pressure gauge on the line between the device and the air source. Water may condense in the lines when not in use and this water must be removed. There are two ways to remove the water: use of a water trap or purging the lines before use. If a water trap is used, it shall be installed on the air line in such a manner to prevent condensed water from entering the slurry. This device shall not be used in referee testing.

NOTE 7—Use of this device or others, causes differing amounts of dispersion and should be used with caution. Information on how to appropriately use this device should be obtained from the manufacturer. 0.0024 m^3/s is equivalent to 5 ft^3/min. The device typically needs at least 0.0009 m^3/s (2 ft^3/min) to operate and therefore, some small air compressors are not capable of supplying sufficient air to operate the device.

6.13 *Agitator (Optional/Referee)*—A hand-held device to mix the soil suspension in the sedimentation cylinder prior to testing, as shown in Fig. 3. The agitator must not have any type of metal, such as a screw head, protruding from the bottom of the disk. To aid in strengthening the connection between the rod and the disk, a smaller disk (about 25 mm or less) having similar thickness and material as the larger disk, may be



Type A **Type B**

Dimensional Equivalents[A]	
mm	in.
19	0.75
13	0.51
5.16 ± 0.03	0.203 ± 0.001
1.24	0.049 (No. 18 BW Ga.)
Note: All dimensions are shown in millimetres unless otherwise noted.	

[A] The SI units presented are basically soft conversions of the inch-pound units; other rationalized SI units should be acceptable providing they meet the technical requirements established by the inch-pound apparatus.

FIG. 1 Detail of Stirring Paddles

inserted on top of and in the center of the larger disk. This device shall be used for referee testing.

6.14 *Agitation of the Soil Slurry*—Any of the following items may be used to break up the soil aggregations as described in 11.1:

6.14.1 *Erlenmeyer Flask*—A glass flask having a capacity between 250-mL and 500-mL.

6.14.2 *Dispersion Shaker*—A platform, wrist action or similar type shaker having a gyratory, orbital, reciprocating, or similar motion to assist in the dispersion process by continuously agitating the soaking soil.

6.14.3 *Ultrasonic Water Bath*—The ultrasonic water bath must be large enough to hold a beaker or flask containing the soil slurry to be agitated for use in the sedimentation test. The water level in the bath should be equal to or higher than the water level in the specimen container.

6.15 *Desiccator (Optional)*—A desiccant containing device of suitable size used to prevent moisture gain during cooling of the oven-dried specimen.

6.16 *Mortar and Rubber-Covered Pestle (Optional)*—Apparatus suitable for breaking up aggregations of air-dried soil particles without breaking individual particles.

6.17 *Miscellaneous Items*—Items such as a wash/rinse bottle (squirt bottle), rubber scraper, spatula, and stirring rod may be useful.

7. Reagents and Materials

7.1 *Sodium Hexametaphosphate* $(NaPO_3)_6$—Also referred to as sodium metaphosphate is the dispersion agent (deflocculant) required to prevent the fine particles in suspension from coalescing or flocculating (Note 8). Consult the Safety Data Sheet (SDS) for specific information regarding this chemical.

7.2 *Isopropyl Alcohol*—Also referred to as isopropanol alcohol or rubbing alcohol is used as a foam inhibitor. Commercially available in concentrations ranging from 70 % to 99 %.

7.3 *Test Water*—Distilled or demineralized water is the only permissible test fluid. The use of tap water is not permitted.

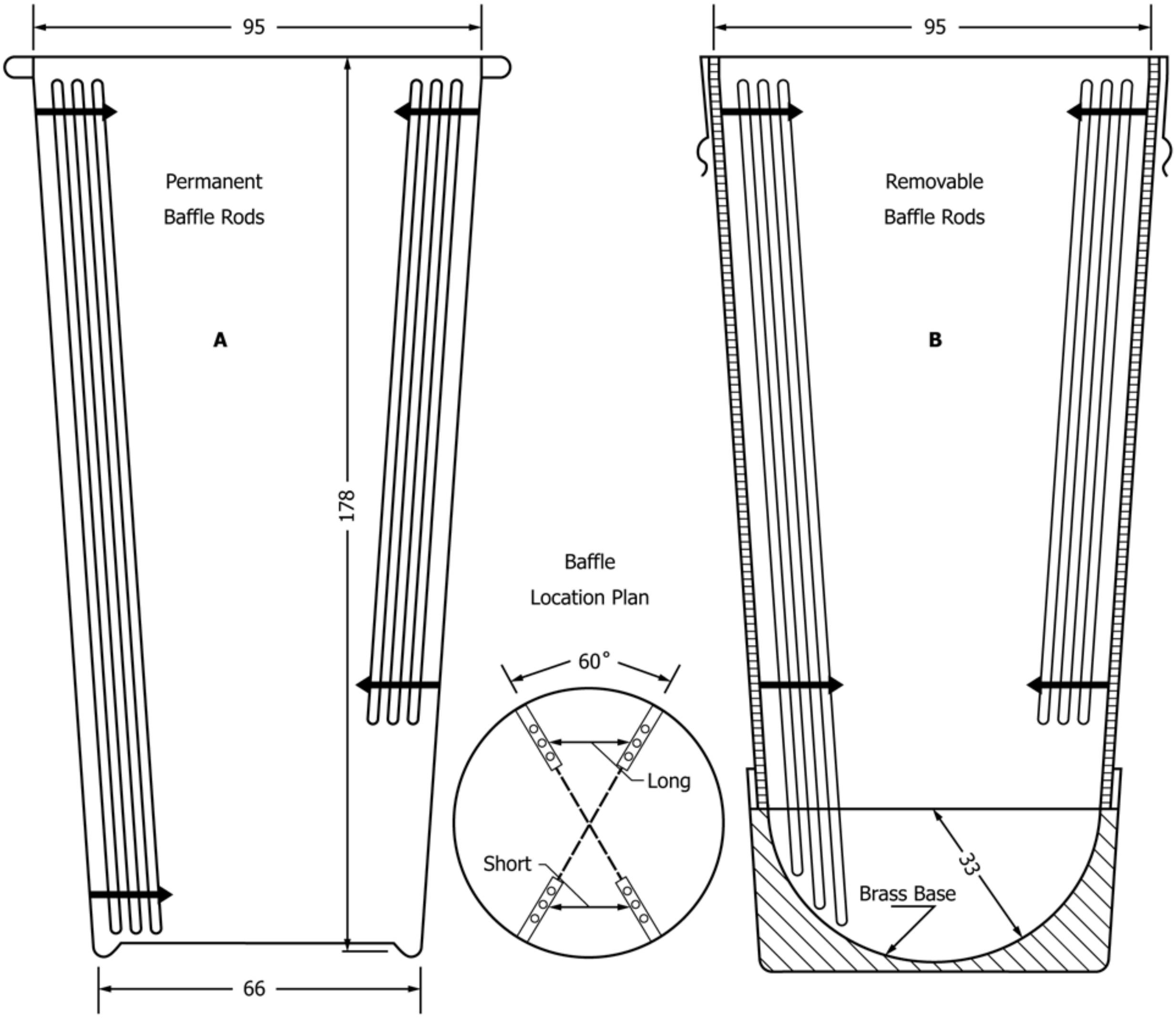
NOTE 8—Fine-grained soils requiring the use of a dispersant are those that do not readily slake in water, such as some highly plastic clays and most tropical soils. Typically, 5 grams per test of dispersant is used to prevent flocculation and is added directly to the soil, such that the concentration will equal 5 g/L in the final soil suspension volume. The chemical formula for the dispersant shown above is approximate.

8. Sampling

8.1 *General*—This test method does not address, in any detail, procurement of the sample. It is assumed the sample is obtained using appropriate methods and is representative of the material under evaluation. However, the testing agency shall preserve all samples in accordance with Practice D4220/D4220M, Group B, except if the as-received sample does not meet those requirements. In which case, the water content of the material does not have to be maintained.

8.2 Where data from this test are to be used for correlation with other laboratory or field test data, use the same material as used for these tests where possible and as much is practical.

8.3 The sample can be from a variety of sources and contain a wide range of particle sizes. Typically, samples for particle-size analysis are obtained from the following sources: large bags or buckets, small bags, jar samples, tube samples, or



Dimensional Equivalents[A]	
mm	in.
33	1.30
66	2.60
95	3.75
178	7.01

Note: All dimensions are shown in millimetres unless otherwise noted.

[A] The SI units presented are basically soft conversions of the inch-pound units; other rationalized SI units should be acceptable providing they meet the technical requirements established by the inch-pound apparatus.

FIG. 2 Dispersion Cup

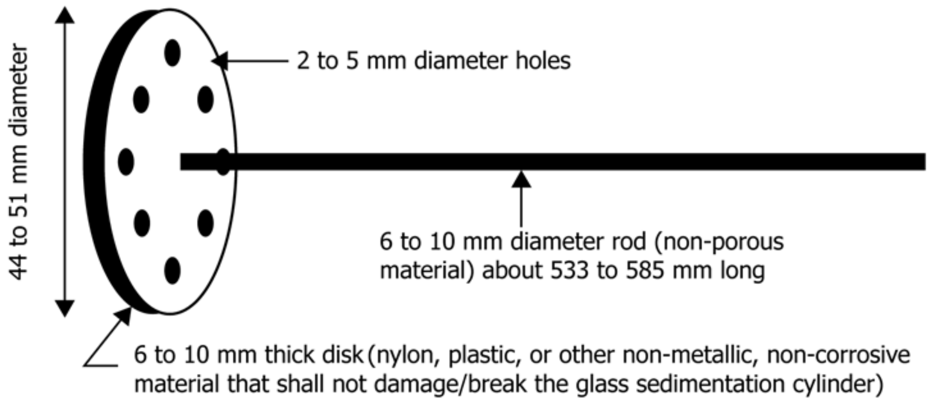
specimens from other tests, such as consolidation, hydraulic conductivity or strength tests. In some cases, such as compaction testing, prior testing may have caused a reduction in particle sizes; therefore, it may be required to obtain a sample of the original material, the degraded sample, or both. Test Methods D6913, Section 9, gives additional information regarding sampling from the different sources.

8.3.1 Preserve the sample at its original moisture condition unless excluded above, and at no time shall the sample be allowed to undergo undesirable temperature changes such as freezing or heating.

8.4 When the sample contains particles larger than the ⅜-in. (9.5-mm) sieve, it shall be processed to obtain the reduced sample. If particle-size separation is necessary, process the sample to meet this requirement using the separation procedures provided in Test Methods D6913.

8.4.1 The reduced sample shall have a maximum particle size that passes through the ⅜-in. (9.5-mm) sieve.

8.4.2 The mass of the reduced sample shall meet or exceed the mass requirements given in Table 1.



Dimensional Equivalents[A]	
mm	in.
2 to 5	0.0781 to 0.200
6 to 10	0.250 to 0.375
533 to 585	22 ± 1
44 to 51	1.75 to 2.00

Note: All dimensions are shown in millimetres unless otherwise noted.

[A] The SI units presented are basically soft conversions of the inch-pound units; other rationalized SI units should be acceptable providing they meet the technical requirements established by the inch-pound apparatus.

FIG. 3 Detail of Agitator

8.4.3 Preserve the original moisture condition of the reduced sample, and at no time shall the reduced sample be allowed to undergo undesirable temperature changes such as freezing or heating.

9. Preparation of the Test Specimen

9.1 *Specimen Procurement*—This standard presents two preparation methods to obtain the sedimentation specimen from the reduced sample: moist and air-dried. In these preparation methods, moist and air-dried refers to the condition of the material or sample as it is being reduced to an appropriate particle size and mass. The test shall not be performed on oven-dried material. The moist preparation method shall be used for referee testing and for samples not received in the air-dried state. The air-dried method shall only be used on materials received in the air-dried state (Note 9). Since some fine-grained, air-dried soils aggregate, a mortar and rubber covered pestle is used to break up aggregations. Care must be taken to avoid disintegration or reduction of individual particles. Use only enough force as necessary to break up the aggregations without destroying the individual particles. Additional guidance for splitting material to obtain a representative specimen using a splitter, quartering, or moist stockpile sampling is given in Test Methods D6913, Annex A2.

NOTE 9—Air drying causes irreversible changes to the clay particles that cause permanent flocculations and decreases the fine fraction.[3]

9.2 *Moist Preparation (Referee)*—This preparation method shall be used for materials not received in the air-dried state. This method is especially important for any soil whose properties are altered due to drying such as, most organic soils, many highly plastic fine-grained soils, tropical soils and soils containing halloysite. The material is thoroughly mixed to obtain a uniform reduced sample. Intact fine-grained samples should be chopped/reduced into small pieces, less than approximately 13 mm, and mixed to make uniform. Test water can be added to assist in making a uniform sample. There is no need to process the fine-grained materials through a sieve.

9.3 *Air-Dried Preparation*—This preparation method shall only be used if the sample is received in the dried condition. In order to obtain a uniform reduced sample, the sample is blended at room temperature.

9.4 If the reduced sample contains particles which are larger than the No. 10 (2.0-mm) sieve, the material shall be separated using a No. 10 (2.0-mm) or finer sieve. Process the entire reduced sample over the No. 10 (2.0-mm) or finer sieve using a rubber scraper and, if needed, test water to aid in working the material through the sieve. Check that the material retained on the sieve does not contain aggregations of finer particles. Any aggregations should be broken and passed through the sieve. It is not necessary that the separation be totally complete but the material passing the sieve shall be representative. The material passing the separation sieve is termed the sedimentation sample and shall meet the minimum mass requirement of Table 1. Record the separation sieve size that is used to separate the sample.

9.5 Estimate the amount of moist mass needed for the sedimentation test using the equation (Note 10):

$$M_{mest} = H_c \times \left(\frac{100}{\%est}\right) \times \left(1 + \left(\frac{w_{cest}}{100}\right)\right) \qquad (1)$$

where:

M_{mest} = estimated moist mass, nearest 1 g,

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[3] Sridharan, A., Jose, B.T., and Abraham, B.M., Technical Note on "Determination of Clay Size Fraction of Marine Clays," *Geotechnical Testing Journal*, GTJODJ, Vol. 14, No. 1, March 1991, pp. 103-107.

H_c = hydromter capacity, g (either 45 for 151H or 55 for 152H),
$\%est$ = estimated percentage of material passing the No. 200 (75-µm) sieve, nearest 1 %, and
w_{cest} = estimated water content, nearest 1 %.

NOTE 10—The mass of the sedimentation test specimen should be selected based on the amount of material that will be in suspension at the time of the first reading. The capacity of the 152H hydrometer is about 55 g of dry soil and the capacity of the 151H is about 45 g. The wet mass should be adjusted to account for the water content and the fraction of particles larger than the No. 200 (75-µm) sieve. For example, if the water content is estimated at 20 %, using a 151H hydrometer, and an estimated percent passing the No. 200 (75-µm) sieve of 95 %, the estimated moist mass needed is 57 g.

9.6 If the sedimentation sample contains sufficient material, then split or quarter the sedimentation sample into at least two portions: one for the water content determination and one for the sedimentation test. The water content specimen shall contain 50 ± 10 g of material.

9.7 If the sedimentation sample has limited material, reduce the mass to obtain the sedimentation specimen. Do not obtain a water content specimen. Obtain the dry mass, M_d, of the sedimentation specimen at the end of the test as discussed in 11.12 and calculated in 12.1.2.

NOTE 11—If there is enough material after splitting/quartering to obtain the necessary masses for both the sedimentation and water content specimens, the sedimentation sample is considered to have sufficient material. If there is not enough material to obtain both the necessary masses of the specimens, the sedimentation sample is considered to have limited material.

9.8 Record the mass of the moist soil, M_m, used for the sedimentation test to the nearest 0.01 g.

9.9 Place the sedimentation specimen in the specimen-mixing container and record the identification of the specimen-mixing container.

9.10 If sufficient material is available, immediately use the other specimen for determination of the water content in accordance with Test Methods D2216, and record the water content, w_c, to the nearest 0.1 %.

10. Verification/Preparation of Apparatus

10.1 *Hydrometer*—Check and record the dimensions of the 151H or 152H hydrometers as presented in Annex A1 in accordance with the interval listed in the Annex. The hydrometer shall be free of cracks and chips, which can compromise the integrity of the hydrometer. The body and stem of a hydrometer seldom change over time, unless they have been subjected to corrosive materials or have been damaged, that is, chipped or cracked. They only need to be checked before use or after damage has been suspected or seen. Since it is possible for the paper scale inside the hydrometer stem to slide down, the length of the stem above and below the top and bottom graduations, respectively, as well as the hydrometer reading in the test water, shall be checked and documented according to the interval presented in Annex A1 to make sure the scale has remained in its proper place. If the scale has moved, the hydrometer shall be replaced.

10.1.1 *Hydrometer Readings*—Hydrometer readings are taken to the nearest ¼ division (Note 12). Reading the hydrometer can be difficult. A properly placed hydrometer should neither bob nor rotate appreciably when released in the soil suspension. It is important for the stem to be dry and clean when inserting it into the soil suspension. If the stem is wet above the reading point it will add mass to the hydrometer causing the reading to be too low. If the stem is not clean, variations in the meniscus rise will result. In this application, the hydrometers are always read at the top of the meniscus for the reason stated in 10.3.

NOTE 12—Reading the 152H hydrometer to the nearest ¼ division during the first 5 to 8 minutes of the test can be difficult. During that time it is acceptable to read the 152H hydrometer to the nearest ½ division.

10.1.2 To insert the hydrometer correctly do the following: First, make sure the stem is dry. Then, gently hold it by the stem with one or both hands and slowly lower it to the depth at which it just floats. This insertion process should take between 5 to 15 seconds.

10.2 *Temperature-Density Correction*—During a test, the suspension fluid density changes, therefore calculations for the quantity of particles in suspension must account for fluid density changes due to temperature, presence of dispersant and the meniscus rise. The temperature-density correction is shifting the hydrometer scale, which is factory set for distilled water at 20°C. There are two ways to determine this correction: take companion measurements in a control cylinder filled with the reference solution during the testing or generate a reusable, calibration relationship. Both options require the use of a reference solution composed of test water and the same amount of dispersant used in the sedimentation test cylinder. The meniscus correction is automatically accounted for in the temperature-density correction for both options by consistently reading the hydrometer at the top of the meniscus as described in 10.3.

10.2.1 *Reference Solution*—The reference solution shall be prepared with the same amount of dispersant as the soil suspension. Fill a control cylinder to the 1,000 mL mark with a mixture of test water and the same amount of dispersant used in the soil suspension cylinder. The test water and dispersant shall be well mixed such that no visible crystals can be seen and the reference solution shall be agitated to make sure the dispersant is adequately mixed throughout the control cylinder.

10.2.1.1 *Companion Measurements*—Use a control cylinder filled with the reference solution in conjunction with the soil suspension cylinder to obtain the correction. Position the control cylinder in the same temperature controlled location as the test cylinders so that all cylinders are at or near the same temperature. For each hydrometer and temperature reading taken in the soil suspension cylinder, take a corresponding hydrometer reading and temperature reading in the control cylinder. However, it is permissible for one control cylinder hydrometer reading taken at the start of the sedimentation test to be used for the initial series of time readings in the soil suspension up to 30 minutes. It is also permissible for one control cylinder temperature reading taken at the start of the sedimentation test to be used for the initial series of time readings in the soil suspension up to the first 30 minutes if the temperature changes in the soil suspension cylinder vary less than 0.5°C between each temperature reading. Record the elapsed time and the hydrometer and temperature readings of the control cylinder on the data sheet(s) only when measured (Note 13).

NOTE 13—Readings taken in one control cylinder may be used for multiple test cylinders. Therefore, if the hydrometer and temperature readings in the control cylinder are only taken once during the first 30 minutes of the test, only that reading is recorded on each of the data sheet(s) to which it applies. These measured readings are not to be written in for the other times during the first 30 minutes when a measurement was not actually determined.

10.2.2 *Calibration Relationship*—This option generates a general calibration relationship between the hydrometer reading of a control cylinder filled with the reference solution and the temperature, which eliminates the need for companion measurements during the test. A temperature-based general calibration relationship is required and established for each hydrometer. A sedimentation cylinder is filled to the 1,000 mL mark with test water with the same amount of dispersant used in the soil suspension. Be sure the solution is thoroughly mixed and the temperature is allowed to equilibrate. Then insert the hydrometer as described in 10.1.2. Take the reading at the top of the meniscus and record this reading and the temperature of the solution. Rinse the hydrometer well with test water between readings and dry it prior to taking the next reading. Increase/Decrease the temperature of the cylinder, allow it to come to temperature equilibrium and repeat the measurement process. Take at least five different hydrometer and temperature readings within the range of temperatures expected during the sedimentation test. Calculate the constant A or B as discussed below.

10.2.2.1 The 151H hydrometer measures the specific gravity of the fluid relative to distilled water at 20°C. The calibration measurements are used to compute the constant A in the following equation. The standard deviation of the five measurements shall be less than 0.0005. The average value of A is used when computing the temperature-density correction.

$$A = R_{151,t} + (7.784 \times 10^{-6} \times T_t) + (4.959 \times 10^{-6} \times T_t^2) \quad (2)$$

where:

A = average specific gravity shift (151H hydrometer), nearest 0.0001,

$R_{151,t}$ = 151H specific gravity hydrometer at reading, t, in reference solution, readable to 0.00025 or better,

T = temperature at reading, t, readable to 0.5°C or better, and

t = subscript indicating the reading number during calibration.

10.2.2.2 The 152H hydrometer measures the mass of particles (specific gravity of 2.65) in a suspension of distilled water at 20°C. The temperature-density correction provides the offset mass reading for the hydrometer for a specific temperature and dispersant concentration. The calibration measurements are used to compute the constant B in the following equation. The standard deviation of the 5 measurements shall be less than 0.5 g/L. The average value of B is used when computing the temperature-density correction.

$$B = R_{152,t} + (1.248 \times 10^{-2} \times T_t) + (7.950 \times 10^{-3} \times T_t^2) \quad (3)$$

where:

B = average mass reading shift (152H hydrometer), nearest 0.1,

$R_{152,t}$ = mass in reference solution hydrometer at reading, t, readable to 0.25 g/L or better,

T = temperature at reading, t, readable to 0.5°C or better, and

t = subscript indicating the reading number during calibration.

NOTE 14—The equations relating the hydrometer readings to temperature are based on the same water density-temperature expression as used in Test Methods D854. For the 151H specific gravity hydrometer, the constants in the water density-temperature equation from Test Methods D854 are divided by the density of water at 20°C (0.99821 g/mL). For the 152H mass in suspension hydrometer, the constants are multiplied by 1606 setting the scale to read mass of solids in solution for a particle specific gravity of 2.65.

10.3 *Meniscus Correction*—Hydrometers are designed to be read at the fluid surface, however, the fluid is wetting to the glass such that the soil suspension will rise up the hydrometer making a reading at the fluid surface impossible at times. It is common practice to read the hydrometer at the top of the meniscus and it must be taken there even when it is possible to see through the soil suspension. The meniscus rise has a small impact on the effective depth determination since the reading is taken slightly above the surface of the suspension. This rise causes a change to the third significant digit in the computed particle size. The meniscus correction is performed before initial use of the hydrometer and after damage has been suspected or noticed.

10.3.1 The meniscus correction, C_m, as shown in Fig. 4, is determined by inserting the hydrometer with a clean and dry stem and without bobbing into the test water with the proper amount of dispersant. The reading at the top of the meniscus and the reading where the plane of water surface intersects the stem are recorded. The difference between these two readings is the meniscus correction, C_m. In accordance with Test Method E126, the latter reading shall be obtained using the following guidance. Observe a point slightly below the plane of the water surface and raise the line of vision until this surface, seen in an ellipse, becomes a straight line. The point where this line cuts the hydrometer scale is the hydrometer reading. Holding a white card behind the cylinder just below the water level will improve the visibility of the surface. The

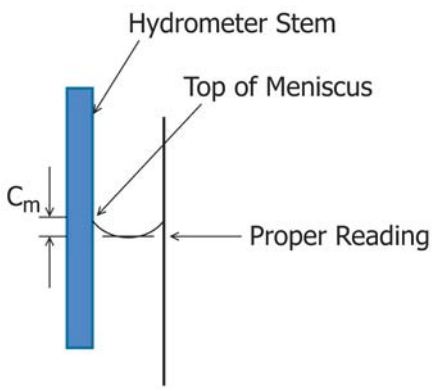


FIG. 4 Meniscus Correction Diagram

hydrometer readings shall be recorded to the nearest ¼ division. The meniscus correction is a positive number for either hydrometer used.

10.4 *Effective Depth*—The effective depth, also referred to as "true depth," is used in the calculation of the particle fall distance for each reading. The effective depth is defined as the center of (volume) buoyancy of the hydrometer to the surface of the soil suspension. The equation to calculate the effective depth when the hydrometer is inserted and removed between readings requires certain dimensional measurements in order to do the calculation. Refer to Fig. 5.

10.4.1 Determine and record the volume of the hydrometer bulb, V_{hb}, to the nearest 1 cm^3 using the procedure given in Annex A1.3.4. The bulb includes everything from the bottom tip up to the base of the stem.

10.4.2 Determine and mark the center of (volume) buoyancy, c_b, using the procedure given in A1.3.5.

10.4.3 Measure the distance between the center of (volume) buoyancy, c_b, and the maximum hydrometer reading H_{r2}, as well as the minimum hydrometer reading, H_{r1}. Record both values to the nearest 0.1 cm. Refer to Fig. 5.

10.4.4 Measure and record the inside cross-sectional area of the sedimentation cylinder, A_c, to the nearest 0.1 cm^2 using the procedure given in A1.4.2.1.

10.5 *Sedimentation Cylinder*—Check and record the dimensions of the sedimentation cylinders as presented in Annex A1 in accordance with the interval presented in Annex A1.

10.6 *Sieves*—See Practice E11 for the verification requirements of the sieves used in this test method.

10.7 *Miscellaneous*—The ancillary equipment used in conjunction with these test methods shall be calibrated/verified/checked according the intervals listed in Practice D3740 and performed in accordance with their applicable standards.

11. Procedure

11.1 Add 5.0 ± 0.1 g of sodium hexametaphosphate to the sedimentation specimen in the specimen-mixing container obtained in 9.9 or dissolve this amount of dispersant in 100 mL of test water and add it to the sedimentation specimen. Record to the nearest 0.01 g the actual amount of dispersant, M_{disp}, placed in the container or dissolved in the test water. If added directly to the sedimentation specimen, add at least 100 mL of test water to the specimen and dispersant to form a slurry of milkshake consistency. The amount of test water to be added during this step should be sufficient enough only to facilitate the process of breaking apart the soil aggregations. Mix the contents with a spatula or similar device until all of the soil aggregations are broken-up (Note 15).

NOTE 15—If hand mixing is not efficient, use a 250 to 500 mL Erlenmeyer flask along with either a wrist or orbital dispersion (mechanical) shaker to vigorously agitate the soil slurry in a minimum of 150 mL of test water for a few hours or until all the soil aggregations are broken-up. Be aware the dispersion cup has a capacity of about 400 mL and the stirring apparatus is only efficient in dispersing soil aggregations that will pass between the baffle rods. An ultrasonic water bath, along with the flask, may also be used to agitate the slurry.

11.2 Prior to the overnight conditioning period, disperse the slurry using either the stirring apparatus or an air jet device.

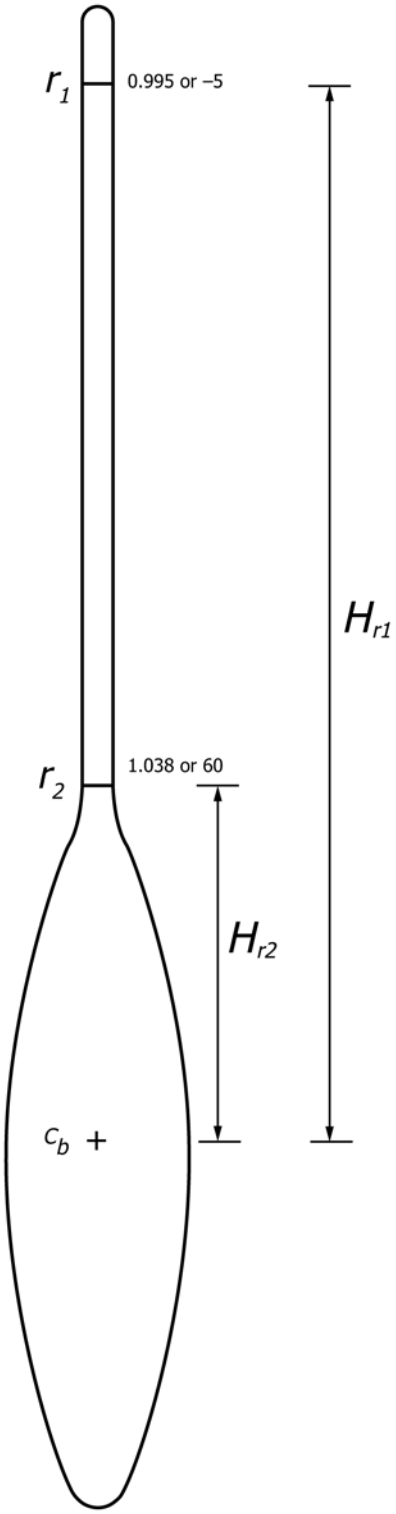


FIG. 5 Effective Depth Dimensional Measurements

11.2.1 If using the stirring apparatus, transfer the slurry to the dispersion cup. Use a wash/rinse bottle filled with test water to aid in the transfer and make sure all of the slurry has been transferred to the dispersion cup. Add additional test water as necessary such that the cup is half full, then use the stirring apparatus to blend the soil for about 1 minute.

11.2.1.1 Transfer all the dispersed slurry into the sedimentation cylinder. Use the wash/rinse bottle filled with test water as needed to make sure all of the slurry is transferred to the cylinder. Add test water to the sedimentation cylinder to bring the bottom of the meniscus of the slurry to the 1,000 mL ± 1 mm mark. Proceed to 11.3.

11.2.2 If using the tube type air jet device, transfer the slurry to the sedimentation cylinder. Use a wash/rinse bottle filled with test water to aid in the transfer and make sure all of the slurry has been transferred to the cylinder. Add additional test water as necessary to bring the volume to no more than 250 mL in the sedimentation cylinder.

11.2.2.1 Before placing the device into the cylinder, slowly allow air to flow until the gauge reads 7 kPa. This initial pressure is needed to prevent the slurry from entering the air jets when the device is inserted into the cylinder and to remove any water that has condensed in the lines. Then, slowly lower the device into the slurry. Make sure the rubber stopper is securely in place at the top of the cylinder to prevent the slurry from being ejected from the cylinder.

11.2.2.2 For clayey soils increase the pressure to 172 kPa and for sandy soils increase the pressure to 69 kPa. Once the pressure is reached, disperse the slurry for five minutes. At the end of five minutes, reduce the pressure to 7 kPa and lift the air jets out of the slurry and wash any slurry remaining on the device back into the cylinder. Once the device is washed off, turn off the air flow to the device and add test water to the sedimentation cylinder to bring the bottom of the meniscus of the slurry to the 1,000 mL ± 1 mm mark. Proceed to 11.3.

11.3 Mix the slurry using the agitator (referee) or the tipping method (Note 16). The agitator device is the preferred/referee method for mixing. Check for the presence of foam on top of the slurry after mixing. If a significant amount of foam is present, it may be necessary to reduce the foam using isopropyl alcohol just prior to the start of testing (See 11.7.1).

11.3.1 To use the agitator, insert the paddle to the lower ¼ of the cylinder. Stroke the agitator at a rate of about one cycle per second over a distance of several centimeters to dislodge any material stuck to the bottom of the cylinder. After the material is dislodged, the agitator should be rapidly moved downwards until the paddle almost comes into contact with the bottom of the cylinder and then upwards with a slower motion. The downward stroke should take about one to two seconds while the upward stroke should take about two to three seconds. As this process is repeated, the elevation of the starting position of the agitation cycle is raised until the bottom of the agitator is significantly above the mid-height of the soil suspension. Keep the paddle submerged at all times during mixing. Mix for about one minute or until the suspension appears uniform.

11.3.2 To use the tipping method, first place a rubber stopper in the open end of the cylinder or use the palm of the hand to cover the opening. Then turn the cylinder upside down and back for a period of one minute to complete the agitation of the slurry (Note 17). Using the cylinder tipping method is not very efficient and tipping for more than one minute will typically be required when testing highly plastic clays. This method of agitation may leave some soil aggregations. Use of the agitator is greatly encouraged.

NOTE 16—When using the tipping method, there will likely be some soil particles remaining on the rubber stopper or hand and on the sides of the sedimentation cylinder above the 1,000 mL mark. Be careful not to lose much material by scraping the material adhering to the rubber stopper or hand off onto the rim of the cylinder. Do not rinse these particles back into the cylinder. The minor loss of mass (~0.02 g or less, if care is taken) is less critical with respect to the calculations than the addition of water (~5 mL) to the cylinder.

NOTE 17—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 vigorously shaking of the cylinder while it is inverted.

11.4 If using a companion measurement to obtain the temperature-density correction, prepare the reference solution in a control cylinder by dissolving the same amount (5.0 ± 0.1 g) of sodium hexametaphosphate as used in the soil suspension cylinder in test water. Add test water to the sedimentation cylinder to bring the bottom of the meniscus of the solution to the 1,000 mL ± 1 mm mark.

11.5 Cover the cylinder(s) to prevent evaporation and allow the cylinder(s) to sit overnight either in a temperature controlled insulated chamber or water bath or in an area of relatively constant temperature. This conditioning period allows the temperature to equilibrate and for the specimen to deflocculate (Note 18). The soil slurry is now referred to as a soil suspension since the specimen is basically ready for testing.

11.6 At the end of the conditioning period, check the suspension for indications of flocculation (Note 19). If the suspension has indications of flocculation, then the test is invalid and the suspension should be discarded since it has been contaminated with dispersant. A new specimen would need to be treated to prevent flocculation. Such treatment is beyond the scope of this test method.

NOTE 18—Strong interparticle bonding can occur in suspension having high salt concentrations. The dispersant will not be effective in breaking these bonds. In such circumstances the salt should be leached from the soil before proceeding with the sedimentation test. This leaching results in a considerable increase in effort and difficulty to process the material and is not discussed in this standard.

NOTE 19—Flocculation of clay particles can be difficult to detect. Minor flocculation will shift the particle-size distribution (gradation) towards a finer fraction. Moderate flocculation will cause a plateau in the curve as the sedimentation process stops. Major flocculation will completely halt sedimentation at an early stage. Only major flocculation is visually detectable showing a lack of material collected at the bottom of the cylinder, a surface layer of clear fluid, or horizontal cracks in the suspension.

11.7 Once the suspension has temperature equilibrated and deflocculated, the suspension shall once again be mixed to create a uniform suspension. Repeat the mixing procedure as described in 11.3. Upon completion of agitation, make sure the cylinder is on a stable surface and in a location where it will not be subjected to any jarring or disturbance and immediately start the timer as directed in either 11.7.2 or 11.7.3. If using a temperature controlled water bath, immediately place the cylinder back into the water bath after agitation.

11.7.1 If significant foam develops on top of the suspension after mixing, immediately add up to three drops of isopropyl alcohol to the suspension to reduce or eliminate the foam.

11.7.2 If using the agitator, start the timer when the paddle of the agitator breaks the surface of the soil suspension. After removing the agitator allow the "free" liquid on it to drain back into the sedimentation cylinder.

11.7.3 If using the tilting method, start the timer after completion of the last inversion.

11.8 Hydrometer readings shall be taken at elapsed times of approximately, 1, 2, 4, 15, 30, 60, 240, and 1440 minutes. Additional readings can be taken to better define the particle-size distribution (gradation) relationship.

11.8.1 About 15 to 20 seconds before a reading is required, gently place the hydrometer into the sedimentation cylinder to a depth approximately equal to the level at which it will float as described in 10.1.2. At the prescribed elapsed times and when the hydrometer is stable, read and record the hydrometer reading, r_m, to the nearest ¼ division, and record the elapsed time, t_m.

11.8.2 When removing the hydrometer from the suspension, the removal process should take about 5 to 10 seconds and be with a steady motion. Generally there will be a drop of suspension at the tip of the hydrometer. Touch the tip to the inside lip of the cylinder and allow the drop to flow back into the cylinder.

11.8.3 With a spinning motion, place the hydrometer into a wash cylinder filled with test water to clean off the hydrometer (Note 20). Once the hydrometer is clean, remove and dry it off prior to the next reading or the reading in the control cylinder if using companion measurements.

NOTE 20—While it is ideal to rinse the hydrometer off in a wash cylinder that can be easily cleaned, it is permissible to rinse the hydrometer in another suitable container filled with test water providing there is ample room for the hydrometer to spin.

11.9 Immediately after taking a hydrometer reading, gently insert the thermometric device into the soil suspension and record the temperature, T_m, to the nearest 0.5°C or better. Do not allow the thermometric device to create disturbance in the suspension. After removing the thermometric device, cover the cylinder to prevent evaporation when the time between the readings exceeds five minutes.

11.9.1 The temperature reading taken at the start of the sedimentation test may be used for the initial series of time readings up to 30 minutes. The temperature does not need to be measured more frequently than 30 minutes and shall be recorded at the elapsed times of actual measurements.

11.10 When using a companion measurement to determine the temperature-density correction, the hydrometer, $r_{d,m}$, and temperature, T_m, readings of the control cylinder shall be measured and recorded in accordance with 10.2.1.1.

11.11 If the dry mass, M_d, of the sedimentation specimen has been or will be determined from a companion specimen, the soil suspension is now ready to be washed over the No. 200 (75-µm) sieve.

11.11.1 Pour the soil suspension over the No. 200 (75-µm) sieve. Take care in transferring the soil suspension from the cylinder to the wash sieve so as not to lose material. Make sure there is no remaining material in the cylinder and that the wash water is running clear before transferring the material retained on the sieve into the oven drying container. Record the identification of the container and proceed to 11.13.

11.12 If the dry mass, M_d, of the sedimentation specimen was not determined using the water content taken in 9.10, then the dry mass is obtained from the soil suspension used for the sedimentation test.

11.12.1 After the last hydrometer reading is obtained, transfer all of the soil suspension to the oven drying container as described in 6.11. To facilitate the complete removal of all of the suspension, agitate the cylinder to distribute the soil as described in 11.3 (Note 21). Pour the agitated suspension into the container and record the identification of the container. If using the container as the tare to calculate the dry mass, also record the mass of the container prior to adding the suspension to the nearest 0.01 g. Use a wash/rinse bottle to aid in transferring the slurry.

NOTE 21—It is not necessary to duplicate the exact requirements of 11.3 in order to sufficiently distribute the soil. Use only as many turns (tipping method) or strokes (agitator method) as needed to dislodge the material from the bottom of the cylinder. The purpose of this agitation is to reduce the amount of additional water needed to remove all of the suspension from the cylinder. Additional test water may be added to thoroughly clean the cylinder and remove all of the suspension.

11.12.2 Dry the suspension to a constant mass in the drying oven at 110 ± 5°C. Usually constant mass is achieved after 24 hours when forced-draft type ovens are used. If there is any uncertainty if the specimen has thoroughly dried, it is necessary to perform the constant mass test after an additional six hours in the drying oven, to verify it has indeed completely dried before proceeding (Note 22).

NOTE 22—Determining the dry mass after the test adds additional time and consideration. Because the oven must remove large amounts of water, the drying time takes longer and the constant mass check interval is extended. The large surface area of the specimen in the container allows the material to potentially absorb more moisture from the air as it cools.

11.12.3 Remove the container from the drying oven and allow it to cool in a desiccator or a tightly covered/sealed container. After the container has cooled, determine and record the dry mass of the soil plus dispersant, M_{dd}, to the nearest 0.01 g.

11.12.4 After recording the dry mass of soil plus dispersant, M_{dd}, cover the specimen with tap water and allow the specimen to soak. During soaking, gently stir the specimen to facilitate the separation of particles. Pour the soaked material over the No. 200 (75- µm) sieve. Take care in transferring the soil suspension from the container to the wash sieve so as not to lose material. Make sure there is no remaining material in the container and that the wash water is running clear before transferring the material retained on the sieve into the oven drying container. Record the identification of the container if a different container is used and proceed to 11.13.

NOTE 23—Test Methods D1140 provides information on the washing technique to use.

11.13 Dry the retained material to a constant mass in the drying oven at 110 ± 5°C. Usually constant mass is achieved overnight (~12-16 hours) when forced-draft type ovens are used. If there is any uncertainty if the specimen has thoroughly dried, perform the constant mass test after an additional two hours in the drying oven, to verify it has indeed completely dried before proceeding.

11.14 Remove the container from the drying oven and allow it to cool in a desiccator or cover the container with a tight fitting lid. After the container has cooled, determine and record the dry mass of the soil retained on the No. 200 (75-µm) sieve, M_{dr}, to the nearest 0.01g. During the washing process, the dispersant has been removed and the resulting dry mass will only include the particles retained on the sieve.

12. Calculations

12.1 Calculate the dry mass, M_d, of the sedimentation specimen using either of the following methods.

12.1.1 *Dry Mass Using Moist Mass and Water Content*—Using the water content, w_c, of the companion specimen determined in 9.6 and the initial moist mass, M_m, of the sedimentation specimen, calculate the dry mass of the sedimentation specimen based as follows:

$$M_d = \frac{M_m}{1 + \left(\frac{w_c}{100}\right)} \tag{4}$$

where:

M_d = mass of dry soil, nearest 0.01 g,
M_m = mass of moist soil, nearest 0.01 g, and
w_c = water content, nearest 0.1 %.

12.1.2 *Dry Mass Using The Sedimentation Specimen*—Calculate the dry mass, M_d, of the sedimentation specimen based on the oven-dried material as obtained in 11.12 using the following equation:

$$M_d = M_{dd} - M_{disp} \tag{5}$$

where:

M_d = mass of dry soil, nearest 0.01 g,
M_{dd} = mass of dry soil plus dispersant, nearest 0.01 g, and
M_{disp} = mass of dispersant, nearest 0.01 g.

12.2 *Temperature-Density Correction: Calibration Relationships*—When using the calibration relationship to determine the hydrometer offset reading, $r_{rd,m}$, calculate the corrected hydrometer reading using the equation below that corresponds to the hydrometer used during the test.

12.2.1 For the 151H hydrometer, compute the offset reading for each sedimentation test reading using the following equation:

$$r_{d,m} = A - 7.784 \times 10^{-6} \times T_m - 4.959 \times 10^{-6} \times T_m^2 \tag{6}$$

where:

$r_{d,m}$ = 151H specific gravity hydrometer offset at reading, *m*, nearest 0.0001 (dimensionless),
A = average specific gravity shift (151H hydrometer), nearest 0.0001 (dimensionless),
T = temperature at reading, *m*, readable to 0.5°C or better, and
m = subscript indicating the reading number during the sedimentation test.

12.2.2 For the 152H hydrometer, compute the offset reading value for each sedimentation test reading using the following equation:

$$r_{d,m} = B - 1.248 \times 10^{-2} \times T_m - 7.950 \times 10^{-3} \times T_m^2 \tag{7}$$

where:

$r_{d,m}$ = 152H g/L hydrometer offset at reading, *m*, nearest 0.1 g/L,
B = average mass shift (152H hydrometer), nearest 0.1 g/L,
T = temperature at reading, *m*, readable to 0.5°C or better, and
m = subscript indicating the reading number during the sedimentation test.

12.3 *Temperature-Density Correction: Companion Measurement*—When using the companion measurement to obtain the temperature-density correction, use the recorded hydrometer offset reading taken in the control cylinder, $r_{d,m}$, that corresponds to the hydrometer used during the test.

12.4 *Mass Percent Finer*—For each hydrometer reading taken in the soil suspension, compute the mass of material still in suspension as a percentage of the sedimentation specimen using the appropriate equation for the type of hydrometer used during the test.

12.4.1 For each 151H hydrometer reading, calculate and record the mass percent finer using the following equation:

$$N_m = \left(\frac{G_s}{G_s - 1}\right)\left(\frac{V_{sp}}{M_d}\right)\rho_c(r_m - r_{d,m}) \times 100 \tag{8}$$

where:

N_m = mass percent finer material at reading *m*, nearest 1 %,
V_{sp} = volume of suspension, nearest 0.1 cm^3,
ρ_c = mass density of water at the temperature of manufacturer calibrated, g/cm^3 (Note 24),
M_d = dry soil mass of the sedimentation specimen, nearest 0.01 g,
G_s = specific gravity of soil, nearest three significant digits, (dimensionless),
r_m = hydrometer reading in suspension at reading *m*, readable to 0.00025 (dimensionless),
$r_{d,m}$ = hydrometer offset reading from reference solution at same temperature as reading *m*, nearest 0.0001 (dimensionless), and
m = subscript indicating the reading number during the sedimentation test.

NOTE 24—The mass density of water at the time of calibration is dependent upon the temperature at time of calibration. H151 and H152 hydrometers are calibrated to 20°C, which gives a mass density of 0.98821 g/cm^3.

12.4.2 *Mass Percent Finer*—For each 152H hydrometer reading, calculate and record the mass percent finer using the following equation:

$$N_m = 0.6226 \times \left(\frac{G_s}{G_s - 1}\right) \times \left(\frac{V_{sp}}{M_d}\right)(r_m - r_{d,m}) \times \left(\frac{100}{1000}\right) \tag{9}$$

where:

0.6226 = correction factor to adjust for particle specific gravity,

r_m = hydrometer reading in suspension at reading m, readable to 0.25 g/L, and
$r_{d,m}$ = hydrometer offset reading from reference solution at same temperature as reading m, nearest 0.1 g/L.

12.5 *Effective Depth*—This value is used in the calculation of the particle fall distance for each hydrometer reading. The following equation is used to calculate the travel distance of the particles when the hydrometer is inserted immediately before a reading and is removed until the next reading.

$$H_m = H_{r2} + \left(\frac{(H_{r1} - H_{r2})}{(r_2 - r_1)} \times (r_2 - r_m + C_m) \right) - \left(\frac{V_{hb}}{2A_c} \right) \tag{10}$$

where:

H_m = distance particles fall at reading m when the hydrometer is inserted only for an individual reading, 2 significant digits, cm,
V_{hb} = volume of the hydrometer bulb up to the base of the stem, nearest 1 cm^3,
A_c = cross-sectional area of the sedimentation cylinder, nearest 0.1 cm^2,
H_r = distance between the center of (volume) buoyancy and the minimum (H_{r2}) and maximum (H_{r1}) hydrometer readings nearest 0.1 cm,
r_m = hydrometer reading in suspension at reading m, 151H: readable to 0.00025 (dimensionless) 152H: readable to 0.25 g/L,
C_m = meniscus correction: 151H nearest 0.25 division (dimensionless) 152H: nearest 0.25 g/L,
r = the minimum (r_2) and maximum (r_1) hydrometer reading (dimensionless or g/L), and
m = subscript indicating the reading number during the sedimentation test.

12.6 *Maximum Particle Diameter in Suspension*—For each hydrometer reading, calculate and record the particle diameter of the soil using the following equation:

$$D_m = \left(\sqrt{\frac{18\mu}{\rho_w g (G_s - 1)} \cdot \frac{H_m}{t_m}} \right) \times 10 \tag{11}$$

where:

D_m = particle diameter, two significant digits, mm,
μ = viscosity of water at 20°C, 0.0100 g/cm-s,
ρ_w = mass density of water at 20°C, 0.99821 g/cm^3,
g = acceleration dues to gravity, 980.7 cm/s^2,
G_s = specific gravity of soil, three significant digits (dimensionless),
t_m = elapsed (fall) time, two significant digits, s,
H_m = particle fall distance, two significant digits, cm, and
m = subscript indicating the reading number during the sedimentation test.

12.7 *Percent Passing the No. 200 (75-µm)*—Calculate the percent passing the No. 200 (75-µm) sieve using the following equation:

$$P_p = 100\left(1 - \frac{M_{dr}}{M_d} \right) \tag{12}$$

where:

P_p = percent passing the No. 200 (75-µm) sieve, nearest 0.1 %,
M_d = initial dry mass of the sedimentation specimen without dispersant, nearest 0.01 g, and
M_{dr} = dry mass retained on the No. 200 (75-µm) sieve, nearest 0.01 g.

13. Report: Test Data Sheet(s)/Form(s)

13.1 The methodology used to specify how data are recorded on the test data sheet(s)/form(s), as given below, is covered in 1.13 and in Practice D6026.

13.2 Record as a minimum the following general information (data):

13.2.1 Identification of the material being tested, such as the project identification, boring number, sample number, and depth.

13.2.2 Test number, if any, testing dates and the initials of the person(s) who performed the test.

13.2.3 The sample preparation method used: moist or air-dried

13.2.4 The specific gravity of the sedimentation specimen and indicate if the value is assumed or measured.

13.2.5 The following apparatus identification used during the test:

13.2.5.1 Hydrometer type (151H or 152H) and identification number.

13.2.5.2 Sedimentation cylinder identification number.

13.2.5.3 Thermometric device identification number.

13.2.5.4 Balance identification number.

13.2.5.5 Oven identification number.

13.2.5.6 Wet washing sieve identification number.

13.2.6 Description and classification of the soil in accordance with Practice D2488 or when Atterberg limit data are available, Practice D2487.

13.2.7 Describe any material that was excluded from the specimen.

13.2.8 Describe any problems that were encountered.

13.2.9 Indicate any prior testing performed on the specimen.

13.3 Record as a minimum the following test specimen data:

13.3.1 The size of the separation sieve used.

13.3.2 The estimated percentage passing the No. 200 (75-µm) sieve, moist mass, and water content calculated or used in 9.5.

13.3.3 The water content of the material passing the No. 10 (2.0 mm) or finer sieve, if determined.

13.3.4 Moist mass of the sedimentation specimen.

13.3.5 Dry mass of the sedimentation specimen and indicate how obtained: using companion water content or direct measurement after testing.

13.3.6 Amount of dispersant used in the test.

13.3.7 The dry mass of the specimen plus dispersant, if applicable.

13.3.8 The percent passing the No. 200 (75-µm) sieve.

13.3.9 The start time and date of the test.

13.3.10 Indicate if a foam inhibitor was used.

13.3.11 The maximum particle diameter of the material for each hydrometer reading.

13.3.12 The mass percent finer for each hydrometer reading.

13.3.13 The hydrometer, temperature, elapsed time, offset, and effective depth readings from the sedimentation test.

13.3.14 Tabulation of the mass percent finer including the particle diameter in mm.

13.3.15 A graph of the percent passing versus the log of particle size in mm.

NOTE 25—Appendix X1 shows an example data sheet and an example of the graphical display of the results of the test.

14. Precision and Bias

14.1 *Precision*—Test data on precision is not presented due to the nature of the soil materials tested by this test method. An ISR round-robin testing program was conducted; however, the data has not yet been compiled. Subcommittee D18.03 is in the process of determining how to report the data from the ISR round-robin testing.

14.2 *Bias*—There is no accepted reference value for this test method, therefore bias cannot be determined.

15. Keywords

15.1 clay; grain-size; hydrometer analysis; particle-size distribution (gradation); sedimentation; sieve analysis; silt

ANNEX

A1. CHECK OF HYDROMETER AND SEDIMENTATION CYLINDER

(Mandatory Information)

A1.1 *General*—There are many factors controlling the overall accuracy of sedimentation (hydrometer) test results. This section covers how the equipment constants used in calculating the sedimentation (hydrometer) test results are determined or checked. The equipment tolerances for the hydrometer and sedimentation cylinder are presented below.

A1.2 *Hydrometer Standard Dimensions* —The 152H and 151H hydrometers have specified dimensions in accordance with Specification E100, as shown in Fig. A1.1, and the hydrometer constants or equipment accuracy checks are listed with the accepted tolerances and summarized below.

A1.2.1 The distance from the key reference point on the nominal scale to the top or bottom of the hydrometer bulb H_t and H_b in mm. The key reference point on the nominal scale for 152H hydrometers is 0.0 g/L and 1.000 specific gravity for a 151H hydrometer.

A1.2.1.1 $H_t = 103 – 130$ mm, with an average of 116.5 mm.

A1.2.1.2 $H_b = 244 – 246$ mm.

A1.2.2 The overall length of the hydrometer bulb, H_{Lb} in mm.

A1.2.2.1 $H_{Lb} = 115 – 142$ mm, with an average of 128.5 mm.

A1.2.3 The distance from the top or bottom of the hydrometer's bulb to the maximum diameter of the bulb, H_{ct} or H_{cb} in mm (Note A1.1).

NOTE A1.1—It is possible for the maximum diameter and the center of (volume) buoyancy to have different locations on the bulb. When calculating effective depth, the location of the center of (volume) buoyancy should be used to calculate H_{r1} and H_{r2}, not the location of the maximum diameter.

A1.2.3.1 H_{ct} or $H_{cb} = 58 – 71$ mm, with an average of 64.5 mm assuming the volume of the bulb is symmetrical.

A1.2.4 The distance from the key reference point on the nominal scale to the center of the bulb's volume, H_{Lc} in mm.

A1.2.4.1 $H_{Lc} = 174 – 188$ mm, with an average of 181 mm.

A1.2.5 The length of the quoted nominal scale as stated in Specification E100, H_s in mm.

A1.2.5.1 $H_s = 82 – 84$ mm, with an average of 83 mm.

A1.2.6 The distance between scale divisions, $\varDelta H_s$ in mm/division (Note A1.2).

A1.2.6.1 $\varDelta H_s$ for 152H: Quoted scale of 0 – 50 g/L or 50 divisions, $\varDelta H_s = 1.66 \pm 0.02$ mm. Full (actual) scale is -5 – 60 g/L.

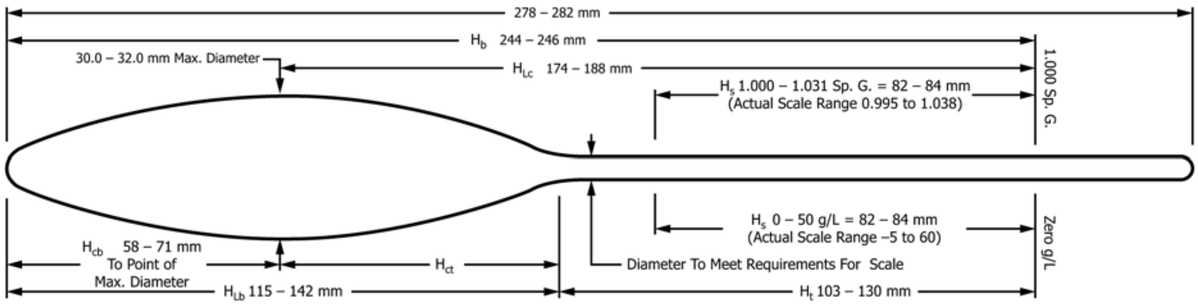


FIG. A1.1 Soil Hydrometer (151H or 152H)

A1.2.6.2 151H: Quoted scale of 1.000 – 1.031 specific gravity or 31 divisions, ΔH_s = 2.68 ± 0.03 mm. Full (actual) scale is 0.995 – 1.038 specific gravity.

A1.2.7 The submerged volume of the hydrometer bulb, V_{hb} in mL or cm^3.

A1.2.7.1 V_{hb} is not a constant and shall be measured for each hydrometer.

A1.2.8 The accuracy of the scale key reference point(s) on the hydrometer scale.

A1.2.8.1 The scale key reference point for the 152H hydrometer is 0.0 ± 1 g/L and 1.000± 0.001 specific gravity for the 151H hydrometer read at the bottom of the meniscus.

A1.2.9 The length of the stem above and below the scale in mm.

A1.2.9.1 Stem shall be uniform and extend at least 15 mm above the top of the graduation and remain cylindrical for at least 3 mm below the lowest graduation.

NOTE A1.2—It is assumed that ΔH_s is uniform over the length of the scale; however, this assumption is not true in accordance with Test Method E126. The equation in Test Method E126 works fine for the 151H hydrometers, but not for the 152H hydrometers since they start at zero. Based on the Test Method E126 equation, the difference in ΔH_s at the top and bottom of the 151H scale is about 6 %.

A1.3 *Checking the Dimensions*—The dimensions provided in A1.2.1 through A1.2.8 shall be checked and documented prior to use. The dimensions provided in A1.2.9 shall be checked and documented once every 12 months. If any of the standard dimensions do not fall within the allowable ranges, the hydrometer shall not be used.

A1.3.1 *Distance/Length*—The length dimensions shall be made and recorded to the nearest 0.5 mm. They can be made using either, and given in order of preference: a height gauge (digimatic, dial, or vernier), calipers (digimatic, dial, or vernier), or a ruler and square (the square is used to transcribe the measurement from the hydrometer to the ruler). The line of contact between the hydrometer stem and bulb can be established and marked using one of two methods. The first choice is to measure the diameter of the stem with calipers, increasing this measurement by about 1 mm and marking the spot where the calipers encounter the bulb. The other method is to visually determine this line of contact and mark it. The visual determination may be assisted by feeling the contact point with fingers. Marking can be accomplished by placing lengthwise a thin strip of label paper/marking tape across the line of contact and then marking it with a pencil.

A1.3.2 *Scale Length*—The quoted scale length shall be measured and recorded to the nearest 0.5 mm using either calipers or a machinist ruler. The distance between scale divisions is simply that length divided by the number of divisions and recorded to the nearest 0.01 mm/div. The error stated in Note A1.1 is ignored.

A1.3.3 *Scale Key Reference Points*—The 152H hydrometer should read 0.0 ± 1 g/L and 1.000 ± 0.001 specific gravity for the 151H hydrometer at the bottom of the meniscus when placed in distilled water that is free of gas bubbles at the calibration temperature of the hydrometers. At temperatures other than the calibration temperature of the hydrometer, the required reading shall be adjusted by the ratio of the density of water at the calibration temperature to the density of water at the check temperature. The check temperature shall be measured to the nearest 0.5°C and the density value associated with that temperature obtained from Table A1.1. If the hydrometer does not read within the allowable range, it shall not be used.

A1.3.4 *Volume*—The volume dimension, V_{hb}, shall be made and recorded to the nearest 1 cm^3 using either the direct or indirect method. The direct method is done by inserting the hydrometer into a graduated cylinder filled with test water having a minimum scale sensitivity of 5 mL per division. Read and record the volume in the cylinder prior to inserting the hydrometer to the nearest 2 mL. Insert the hydrometer into the test water just to the base of the stem then read and record the volume to the nearest 2 mL. The volume of the hydrometer is the difference in the volume readings before and after insertion into the test water. The volume is the average of three determinations that are within 2 mL of each other. The indirect method is done by determining the mass of the hydrometer. The volume can be measured by placing a partially filled beaker of room temperature test water on a balance, zero or tare the balance, and then lowering the hydrometer into the water just to the base of the stem. While holding the hydrometer in place, read and record the mass of displaced water to the nearest 0.1 g. Using an approximate mass density of water equal to unity (1), the volume of the hydrometer bulb in cm^3 will be equal to the mass reading.

A1.3.5 *Center of (Volume) Buoyancy*—Determine the center of (volume) buoyancy using the direct or indirect method described in A1.3.4, except the bulb is inserted until the mass or water level change is half of the volume of the bulb as determined in A1.3.4.

A1.4 *Sedimentation Cylinder Dimensions*—The sedimentation cylinder constants or equipment accuracy checks are listed with the accepted tolerances and summarized below. The cylinder shall be checked and documented prior to use.

A1.4.1 The accuracy of key volume mark is 1,000 ± 5 mL in mL or cm^3.

A1.4.1.1 *Volume*—Verify the 1,000 mL mark is correct by performing the following steps. Place the cylinder on a balance and zero it. Add distilled water free of air bubbles, having a known temperature, T, nearest 1°C, to the cylinder until the balance reads the required mass, M_w. The mass, M_w, in g, equals 1,000 times the density of water, ρ_w, at T taken from Table A1.1. Read the water level at the bottom of the meniscus. The level should be within about 5 mL or ~2 mm of the 1,000 mL mark on the cylinder. If the mark is not correct, remark the cylinder with the correct 1,000 mL line or do not use the cylinder. If the cylinder is remarked, the correct or incorrect line shall be clearly marked as such to prevent misuse of the incorrect line marking. Record the volume to the nearest 0.1 cm^3.

A1.4.2 The inside area, A_c, in cm^2.

A1.4.2.1 *Area*—Determine the inside area of the cylinder, A_c, by using a commercial-grade meter stick or tape measure

TABLE A1.1 Density of Water (ρ_w) Versus Temperature (*T*)[A]

T	ρ_w	*T*	ρ_w	*T*	ρ_w	*T*	ρ_w
(°C)	(g/ML)	(°C)	(g/ML)	(°C)	(g/ML)	(°C)	(g/ML)
15.0	0.99910	16.0	0.99895	17.0	0.99878	18.0	0.99860
.1	0.99909	.1	0.99893	.1	0.99876	.1	0.99858
.2	0.99907	.2	0.99891	.2	0.99874	.2	0.99856
.3	0.99906	.3	0.99890	.3	0.99872	.3	0.99854
.4	0.99904	.4	0.99888	.4	0.99871	.4	0.99852
.5	0.99902	.5	0.99886	.5	0.99869	.5	0.99850
.6	0.99901	.6	0.99885	.6	0.99867	.6	0.99848
.7	0.99899	.7	0.99883	.7	0.99865	.7	0.99847
.8	0.99898	.8	0.99881	.8	0.99863	.8	0.99845
.9	0.99896	.9	0.99879	.9	0.99862	.9	0.99843
19.0	0.99841	20.0	0.99821	21.0	0.99799	22.0	0.99777
.1	0.99839	.1	0.99819	.1	0.99797	.1	0.99775
.2	0.99837	.2	0.99816	.2	0.99795	.2	0.99773
.3	0.99835	.3	0.99814	.3	0.99793	.3	0.99770
.4	0.99833	.4	0.99812	.4	0.99791	.4	0.99768
.5	0.99831	.5	0.99810	.5	0.99789	.5	0.99766
.6	0.99829	.6	0.99808	.6	0.99786	.6	0.99764
.7	0.99827	.7	0.99806	.7	0.99784	.7	0.99761
.8	0.99825	.8	0.99804	.8	0.99782	.8	0.99759
.9	0.99823	.9	0.99802	.9	0.99780	.9	0.99756
23.0	0.99754	24.0	0.99730	25.0	0.99705	26.0	0.99679
.1	0.99752	.1	0.99727	.1	0.99702	.1	0.99676
.2	0.99749	.2	0.99725	.2	0.99700	.2	0.99673
.3	0.99747	.3	0.99723	.3	0.99697	.3	0.99671
.4	0.99745	.4	0.99720	.4	0.99694	.4	0.99668
.5	0.99742	.5	0.99717	.5	0.99692	.5	0.99665
.6	0.99740	.6	0.99715	.6	0.99689	.6	0.99663
.7	0.99737	.7	0.99712	.7	0.99687	.7	0.99660
.8	0.99735	.8	0.99710	.8	0.99684	.8	0.99657
.9	0.99732	.9	0.99707	.9	0.99681	.9	0.99654
27.0	0.99652	28.0	0.99624	29.0	0.99595	30.0	0.99565
.1	0.99649	.1	0.99621	.1	0.99592	.1	0.99562
.2	0.99646	.2	0.99618	.2	0.99589	.2	0.99559
.3	0.99643	.3	0.99615	.3	0.99586	.3	0.99556
.4	0.99641	.4	0.99612	.4	0.99583	.4	0.99553
.5	0.99638	.5	0.99609	.5	0.99580	.5	0.99550
.6	0.99635	.6	0.99607	.6	0.99577	.6	0.99547
.7	0.99632	.7	0.99604	.7	0.99574	.7	0.99544
.8	0.99629	.8	0.99601	.8	0.99571	.8	0.99541
.9	0.99627	.9	0.99598	.9	0.99568	.9	0.99538

[A] Reference: CRC Handbook of Chemistry and Physics, David R. Lide, Editor-In-Chief, 74th Edition, 1993 – 1994.

reading in cm or mm. Insert the meter stick or tape measure into the cylinder until it touches the inside bottom of the cylinder. Read and record the distance from the inside bottom of the cylinder to the 1,000 mL mark to the nearest 1 mm. Repeat this procedure at two more locations on the inside bottom of the cylinder for a total of three readings. Determine and record the average distance, D_{1000}, to the nearest 1 mm. Calculate and record the area of the cylinder, A_c, ($A_c = 1{,}000 \times (10/D_{1000})$) to the nearest 0.1 cm^2.

NOTE A1.3—For example, if the 1,000 mL mark is determined to be 360 mm from the inside bottom of the cylinder, the inside area is 27.8 cm^2 and the diameter is then 59.5 mm. For a 63.5 mm inside diameter cylinder, the 1,000 mL mark should be approximately 316 mm from the inside bottom.

A1.4.3 The inside area's uniformity above the key volume mark.

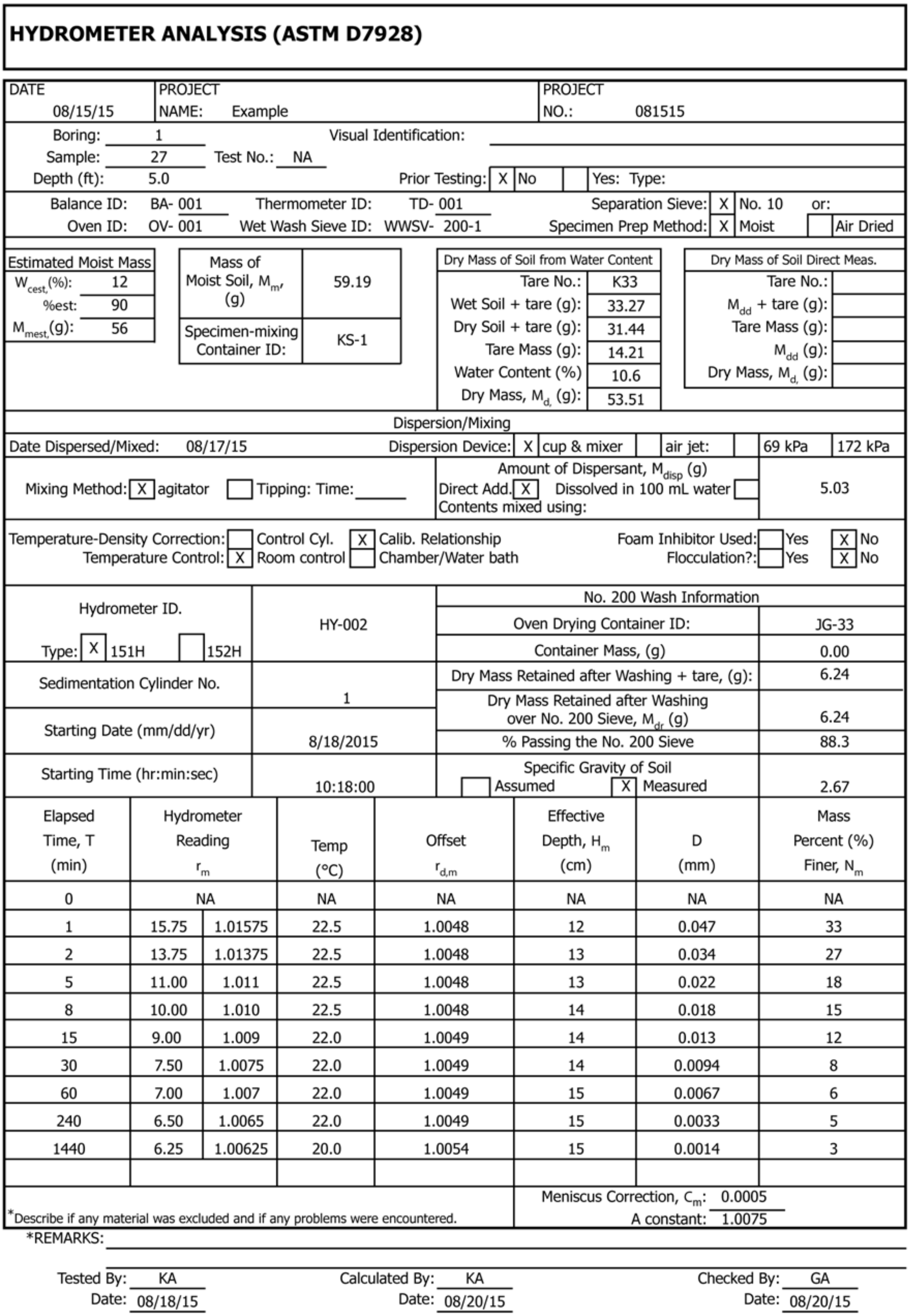
A1.4.3.1 *Area Uniformity*—Determine and record the uniformity of the area above the 1,000 mL. Add 150 ± 1 mL or 150 ± 1g × ρ_w at *T* of bubble free, distilled water to the cylinder filled with 1,000 mL of distilled water. If the water surface raises 150 × ($10/A_c$) ± 0.25 mm, then the area is considered uniform. If this tolerance isn't met, the cylinder shall not be used.

APPENDIX

X1. EXAMPLE DATA SHEETS, GRAPH, AND EQUIPMENT CHECKS

(Nonmandatory Information)

X1.1 *General*—The data sheets in Fig. X1.1and Fig. X1.2 are provided as examples to assist the user by showing results of the calculations performed. Fig. X1.3 is provided as an example of how the results of Fig. X1.1 can be displayed graphically. Fig. X1.1 data is calculated using the calibration relationship and Fig. X1.2 data is calculated using the companion cylinder. Figs. X1.4-X1.6 are examples of typical checks of the hydrometer and sedimentation cylinder. Fig. X1.7 is an example of the meniscus correction and determination of the A constant for a 151H hydrometer.



HYDROMETER ANALYSIS (ASTM D7928)

DATE: 08/15/15
PROJECT NAME: Example
PROJECT NO.: 081515

Boring: 1
Visual Identification:
Sample: 27 Test No.: NA
Depth (ft): 5.0
Prior Testing: ☒ No ☐ Yes: Type:

Balance ID: BA- 001
Thermometer ID: TD- 001
Separation Sieve: ☒ No. 10 or:
Oven ID: OV- 001
Wet Wash Sieve ID: WWSV- 200-1
Specimen Prep Method: ☒ Moist ☐ Air Dried

Estimated Moist Mass	
$W_{cest,}$(%):	12
%est:	90
$M_{mest,}$(g):	56

Mass of Moist Soil, M_m, (g)	59.19
Specimen-mixing Container ID:	KS-1

Dry Mass of Soil from Water Content	
Tare No.:	K33
Wet Soil + tare (g):	33.27
Dry Soil + tare (g):	31.44
Tare Mass (g):	14.21
Water Content (%)	10.6
Dry Mass, $M_{d,}$ (g):	53.51

Dry Mass of Soil Direct Meas.	
Tare No.:	
M_{dd} + tare (g):	
Tare Mass (g):	
M_{dd} (g):	
Dry Mass, $M_{d,}$ (g):	

Dispersion/Mixing

Date Dispersed/Mixed: 08/17/15
Dispersion Device: ☒ cup & mixer ☐ air jet: ☐ 69 kPa ☐ 172 kPa
Mixing Method: ☒ agitator ☐ Tipping: Time:
Amount of Dispersant, M_{disp} (g): 5.03
Direct Add. ☒ Dissolved in 100 mL water ☐
Contents mixed using:

Temperature-Density Correction: ☐ Control Cyl. ☒ Calib. Relationship
Temperature Control: ☒ Room control ☐ Chamber/Water bath
Foam Inhibitor Used: ☐ Yes ☒ No
Flocculation?: ☐ Yes ☒ No

Hydrometer ID.: HY-002
Type: ☒ 151H ☐ 152H
Sedimentation Cylinder No.: 1
Starting Date (mm/dd/yr): 8/18/2015
Starting Time (hr:min:sec): 10:18:00

No. 200 Wash Information	
Oven Drying Container ID:	JG-33
Container Mass, (g)	0.00
Dry Mass Retained after Washing + tare, (g):	6.24
Dry Mass Retained after Washing over No. 200 Sieve, M_{dr} (g)	6.24
% Passing the No. 200 Sieve	88.3
Specific Gravity of Soil ☐ Assumed ☒ Measured	2.67

Elapsed Time, T (min)	Hydrometer Reading r_m		Temp (°C)	Offset $r_{d,m}$	Effective Depth, H_m (cm)	D (mm)	Mass Percent (%) Finer, N_m
0	NA		NA	NA	NA	NA	NA
1	15.75	1.01575	22.5	1.0048	12	0.047	33
2	13.75	1.01375	22.5	1.0048	13	0.034	27
5	11.00	1.011	22.5	1.0048	13	0.022	18
8	10.00	1.010	22.5	1.0048	14	0.018	15
15	9.00	1.009	22.0	1.0049	14	0.013	12
30	7.50	1.0075	22.0	1.0049	14	0.0094	8
60	7.00	1.007	22.0	1.0049	15	0.0067	6
240	6.50	1.0065	22.0	1.0049	15	0.0033	5
1440	6.25	1.00625	20.0	1.0054	15	0.0014	3

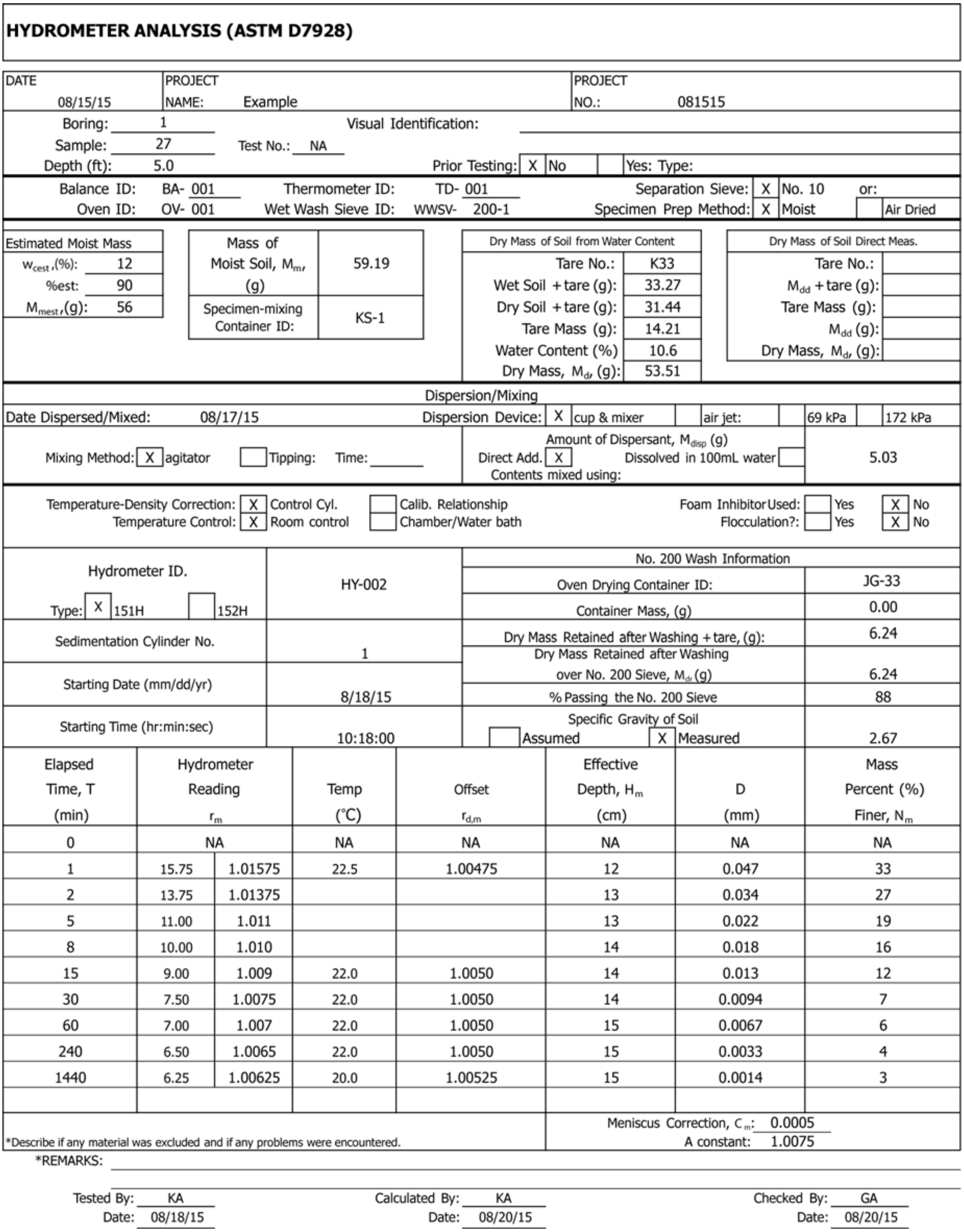
Meniscus Correction, C_m: 0.0005
A constant: 1.0075

*Describe if any material was excluded and if any problems were encountered.

*REMARKS:

Tested By: KA
Date: 08/18/15
Calculated By: KA
Date: 08/20/15
Checked By: GA
Date: 08/20/15

FIG. X1.1 Example Data Sheet Using Calibration Relationship



HYDROMETER ANALYSIS (ASTM D7928)

DATE 08/15/15	PROJECT NAME: Example	PROJECT NO.: 081515

Boring: 1 Visual Identification:

Sample: 27 Test No.: NA

Depth (ft): 5.0 Prior Testing: ☒ No ☐ Yes: Type:

Balance ID: BA- 001 Thermometer ID: TD- 001 Separation Sieve: ☒ No. 10 or:

Oven ID: OV- 001 Wet Wash Sieve ID: WWSV- 200-1 Specimen Prep Method: ☒ Moist ☐ Air Dried

Estimated Moist Mass	
w_{cest},(%):	12
%est:	90
M_{mest},(g):	56

Mass of Moist Soil, M_m, (g)	59.19
Specimen-mixing Container ID:	KS-1

Dry Mass of Soil from Water Content	
Tare No.:	K33
Wet Soil + tare (g):	33.27
Dry Soil + tare (g):	31.44
Tare Mass (g):	14.21
Water Content (%)	10.6
Dry Mass, M_d, (g):	53.51

Dry Mass of Soil Direct Meas.	
Tare No.:	
M_{dd} + tare (g):	
Tare Mass (g):	
M_{dd} (g):	
Dry Mass, M_d, (g):	

Dispersion/Mixing

Date Dispersed/Mixed: 08/17/15 Dispersion Device: ☒ cup & mixer ☐ air jet: ☐ 69 kPa ☐ 172 kPa

Mixing Method: ☒ agitator ☐ Tipping: Time: ______

Amount of Dispersant, M_{disp} (g): 5.03

Direct Add. ☒ Dissolved in 100mL water ☐

Contents mixed using:

Temperature-Density Correction: ☒ Control Cyl. ☐ Calib. Relationship Foam Inhibitor Used: ☐ Yes ☒ No

Temperature Control: ☒ Room control ☐ Chamber/Water bath Flocculation?: ☐ Yes ☒ No

Hydrometer ID. Type: ☒ 151H ☐ 152H	HY-002
Sedimentation Cylinder No.	1
Starting Date (mm/dd/yr)	8/18/15
Starting Time (hr:min:sec)	10:18:00

No. 200 Wash Information	
Oven Drying Container ID:	JG-33
Container Mass, (g)	0.00
Dry Mass Retained after Washing + tare, (g):	6.24
Dry Mass Retained after Washing over No. 200 Sieve, M_{dr} (g)	6.24
% Passing the No. 200 Sieve	88
Specific Gravity of Soil ☐ Assumed ☒ Measured	2.67

Elapsed Time, T (min)	Hydrometer Reading r_m		Temp (°C)	Offset $r_{d,m}$	Effective Depth, H_m (cm)	D (mm)	Mass Percent (%) Finer, N_m
0	NA		NA	NA	NA	NA	NA
1	15.75	1.01575	22.5	1.00475	12	0.047	33
2	13.75	1.01375			13	0.034	27
5	11.00	1.011			13	0.022	19
8	10.00	1.010			14	0.018	16
15	9.00	1.009	22.0	1.0050	14	0.013	12
30	7.50	1.0075	22.0	1.0050	14	0.0094	7
60	7.00	1.007	22.0	1.0050	15	0.0067	6
240	6.50	1.0065	22.0	1.0050	15	0.0033	4
1440	6.25	1.00625	20.0	1.00525	15	0.0014	3

Meniscus Correction, C_m: 0.0005

A constant: 1.0075

*Describe if any material was excluded and if any problems were encountered.

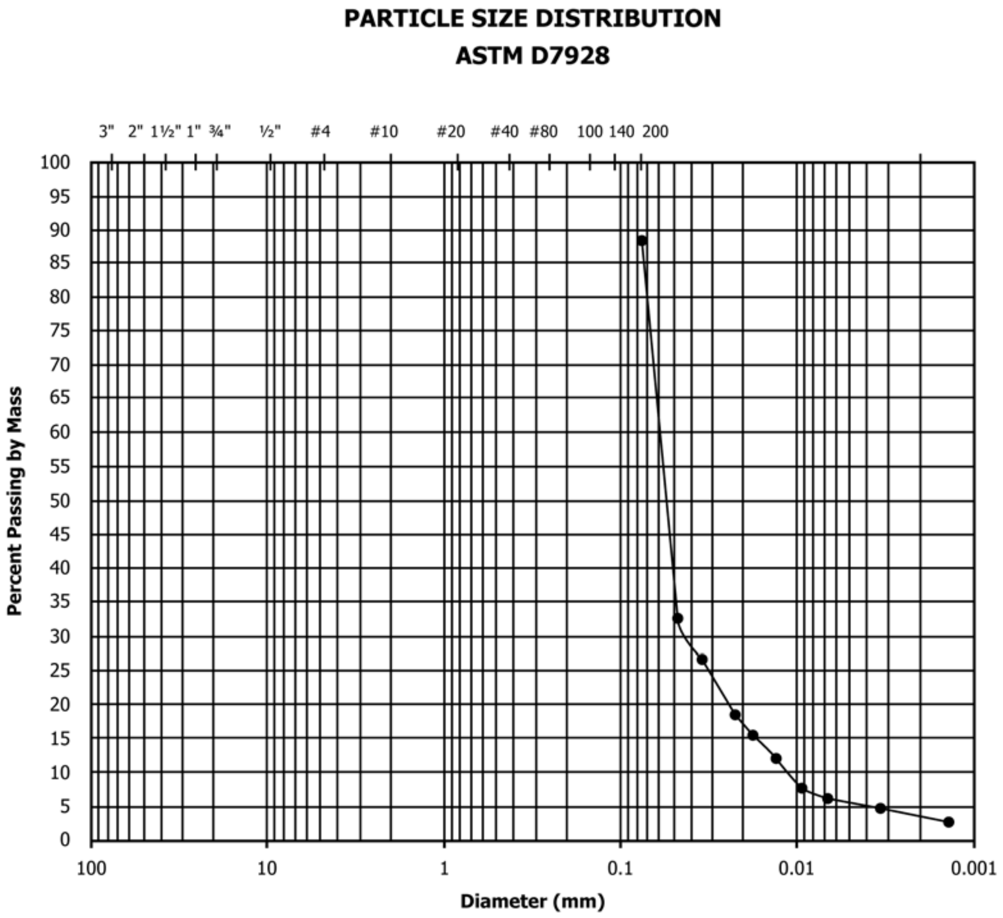
*REMARKS:

Tested By: KA Date: 08/18/15

Calculated By: KA Date: 08/20/15

Checked By: GA Date: 08/20/15

FIG. X1.2 Example Data Sheet Using Companion Measurement



Sand (%)	Fines (%)	
11.7	**88.3**	
	Silt	Clay
	85.0	3.3

Project No.: 081515 -- Project Name: Example
Boring: 1
Sample: 27 - Depth: 5 ft.

FIG. X1.3 Typical Graph of Data

Check of Hydrometers

Procedure: D7928

Date: 08/01/15

Date Due*: Before use/After Repair

Location: Soils Lab

Temperature 22 °C = 72 °F

*1 yr due date for items marked with *.

Check/Standard Equipment

Type:	Caliper
Manufacturer:	Pittsburgh
Model Number:	68304
Serial Number:	NA
Instrument Number:	XCD-001
Date Due:	20/03/16

Type:	Thermometer
Manufacturer:	Hanna
Model Number:	HI935007N
Serial Number:	08617836
Instrument Number:	TD-001
Date Due:	4/2/16

Type:	Balance
Manufacturer:	Sartorius
Model Number:	3102-1S
Serial Number:	0032950176
Instrument Number:	BA-003
Date Due:	6/8/16

Instrument Identification/Data

Type	Hydrometer
Manufacturer	Chase
Model Number	NA
Serial Number	305055
Instrument Number	HY-002 ☒ 151H ☐ 152H
Previous Verification Date:	New

Check Data

	Instrument	PASS/FAIL	Tolerance (mm)
Top of Scale to Top of Hydrometer Bulb, H_t, (mm):	112.0	PASS	103-130
Top of Scale to Bottom of Hydrometer Bulb, H_b, (mm):	246.0	PASS	244-246
Overall Length of Hydrometer Bulb, H_{Lb} (mm):	134.0	PASS	115-142
Top of Hydrometer Bulb to Maximum Diameter, H_{ct}, (mm):	63.0	PASS	58-71
Bottom of Hydrometer Bulb to Maximum Diameter, H_{cb}, (mm)[1]:	71.0	PASS	58-71
Top of Scale (1.000) to Maximum Diameter, H_{Lc}, (mm):	174.0	PASS	174-188
Nominal Scale Length (1.000-1.031 or 0-50 g/L), (mm):	82.0	PASS	82-84
Distance Between Scale Divisions, ΔH_s, (mm/div):	2.65	PASS	1.64-1.68 2.65-2.71
Submerged Volume of Hydrometer Bulb, V_{hb}, (cm^3)[2]:	54	PASS	NA
Scale Reference Point (Sp.Gr or g/L)[3]:	1.001	PASS	1.001-0.999 1.0-1.0
*Stem extends 15 mm above the top graduation?:	Yes	PASS	Yes
*Stem cylindrical for at least 3 mm below lowest graduation?:	Yes	PASS	Yes
Stem Diameter (mm):	5.2	PASS	NA
Center of (Volume) Buoyancy, C_b, (cm^3):	27.0	PASS	NA
Top of Scale (0.995) to Center of Buoyancy, H_{r1}, (mm):	186.0	PASS	NA
Bottom of Scale (1.038) to Center of Buoyancy, H_{r2}, (mm)[1]:	70.0	PASS	NA

[2] Mass of Displaced Water

1 53.9 g

2 53.9 g

3 53.9 g

Avg. 53.9 g

[3] Temperature (°C): 22.0

Scale Rdg: 1.0001

Adj. Rdg: 1.0005

Equip. Status (Conforms/Nonconforms*): ____________

*Who was notified? ____________

Action Taken: ____________

Checked By: KA	Input By: KA	Sticker Applied By: Not Applicable	Checked By: GA
Date: 08/01/15	Date: 08/01/15	Date: –	Date: 08/01/15

FIG. X1.4 Example Hydrometer Check

Check of Sedimentation Cylinders

Procedure: ASTM D7928
Location: Soils Lab

Date: 08/01/15
Date Due: Before Use/After Repair
Temperature 27 °C = 80 °F

Check/Standard Equipment

Type:	Caliper
Manufacturer:	Pittsburgh
Model Number:	68304
Serial Number:	NA
Instrument Number:	XCD-001
Date Due:	3/20/2016

Type:	Thermometer
Manufacturer:	Hanna
Model Number:	HI935007N
Serial Number:	08617836
Instrument Number:	TD-001
Date Due:	4/2/2016

Type:	Balance
Manufacturer:	Sartorius
Model Number:	3102-1S
Serial Number:	0032950176
Instrument Number:	BA-003
Date Due:	6/8/2016

Type:	Tape Measure
Instr. No.:	1
Date Due:	NA

Instrument Identification/Data

Type	Sedimentation Cylinder
Manufacturer	Kimax/Durham Geo
Model Number	NA
Serial Number	NA
Instrument Number	2
Previous Verification Date:	New

Check Data

	Instrument	PASS/FAIL	Tolerance (mm)
Height of Cylinder (mm):	451	PASS	~457
Temperature, °C	27	PASS	NA
Mass of Cylinder with water (g):	1002.1	PASS	NA
Density of Water, g/mL	0.99652	PASS	NA
Inside Area before adjustment, cm^2:	28.1	PASS	22.9-32.2
Calculated Inside Diameter (mm):	60	PASS	55-64
Unadjusted Volume, mL	999	PASS	995-1005
Adjusted Mass of Cylinder w/ water (g):			NA
Adjusted Volume, mL			995-1005
Inside Area after adjustment, cm^2:			22.9-32.2
Area Uniformity (mm):	53.3	PASS	53.2-53.7

	Inside Ht. (mm) Orig.
1	356
2	356
3	356
Avg:	356

	Inside Ht. (mm) Adj.
1	
2	
3	
Avg:	

Amt. added: 149 mL

Equip. Status (Conforms/Nonconforms*): Conforms
*Who was notified?
Action Taken:

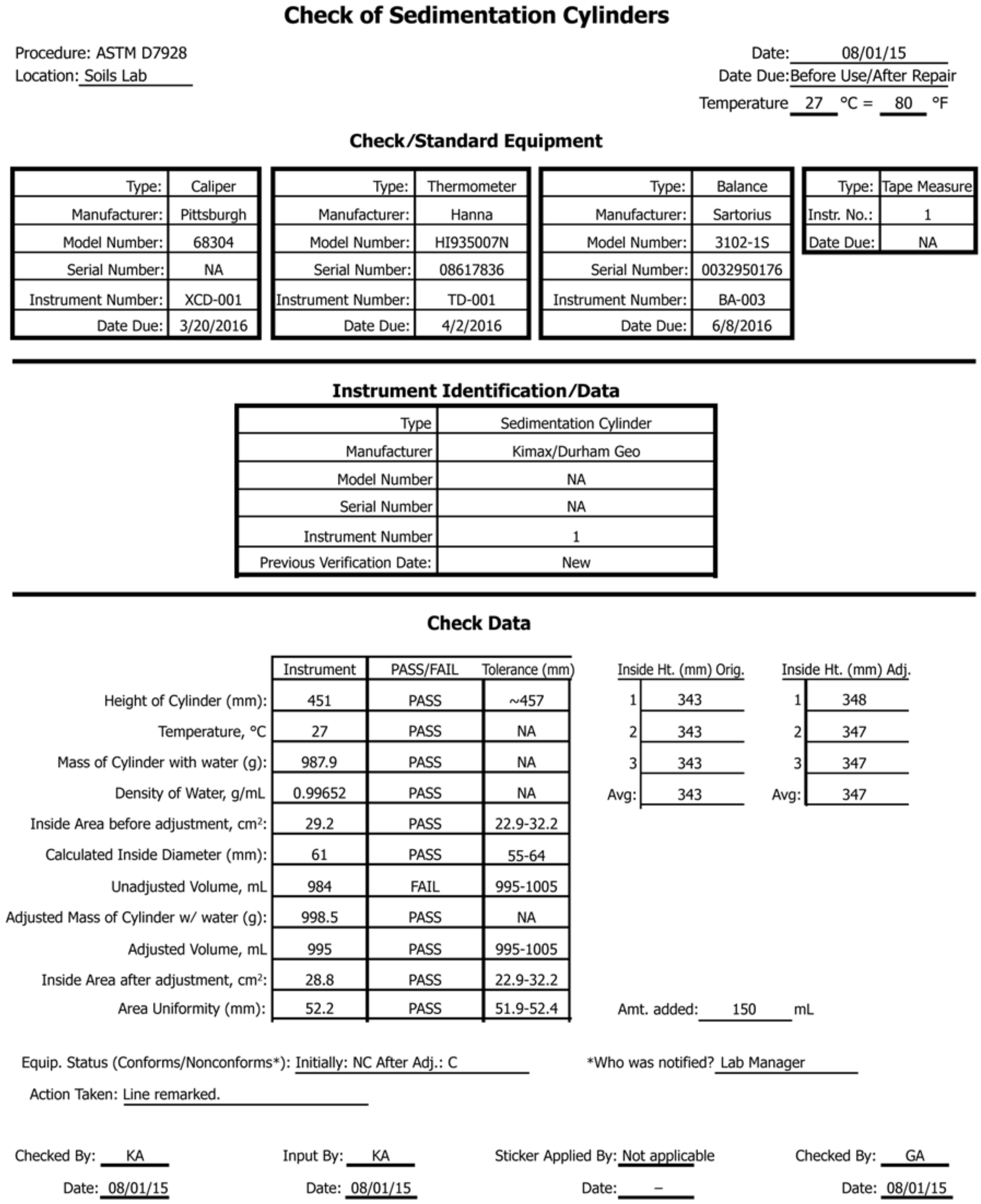
Checked By: KA
Date: 08/01/15

Input By: KA
Date: 08/01/15

Sticker Applied By: Not applicable
Date: –

Checked By: GA
Date: 08/01/15

FIG. X1.5 Example Sedimentation Cylinder Check—No Adjustment



Check of Sedimentation Cylinders

Procedure: ASTM D7928
Location: Soils Lab

Date: 08/01/15
Date Due: Before Use/After Repair
Temperature 27 °C = 80 °F

Check/Standard Equipment

Type:	Caliper
Manufacturer:	Pittsburgh
Model Number:	68304
Serial Number:	NA
Instrument Number:	XCD-001
Date Due:	3/20/2016

Type:	Thermometer
Manufacturer:	Hanna
Model Number:	HI935007N
Serial Number:	08617836
Instrument Number:	TD-001
Date Due:	4/2/2016

Type:	Balance
Manufacturer:	Sartorius
Model Number:	3102-1S
Serial Number:	0032950176
Instrument Number:	BA-003
Date Due:	6/8/2016

Type:	Tape Measure
Instr. No.:	1
Date Due:	NA

Instrument Identification/Data

Type	Sedimentation Cylinder
Manufacturer	Kimax/Durham Geo
Model Number	NA
Serial Number	NA
Instrument Number	1
Previous Verification Date:	New

Check Data

	Instrument	PASS/FAIL	Tolerance (mm)
Height of Cylinder (mm):	451	PASS	~457
Temperature, °C	27	PASS	NA
Mass of Cylinder with water (g):	987.9	PASS	NA
Density of Water, g/mL	0.99652	PASS	NA
Inside Area before adjustment, cm^2:	29.2	PASS	22.9-32.2
Calculated Inside Diameter (mm):	61	PASS	55-64
Unadjusted Volume, mL	984	FAIL	995-1005
Adjusted Mass of Cylinder w/ water (g):	998.5	PASS	NA
Adjusted Volume, mL	995	PASS	995-1005
Inside Area after adjustment, cm^2:	28.8	PASS	22.9-32.2
Area Uniformity (mm):	52.2	PASS	51.9-52.4

	Inside Ht. (mm) Orig.
1	343
2	343
3	343
Avg:	343

	Inside Ht. (mm) Adj.
1	348
2	347
3	347
Avg:	347

Amt. added: 150 mL

Equip. Status (Conforms/Nonconforms*): Initially: NC After Adj.: C

*Who was notified? Lab Manager

Action Taken: Line remarked.

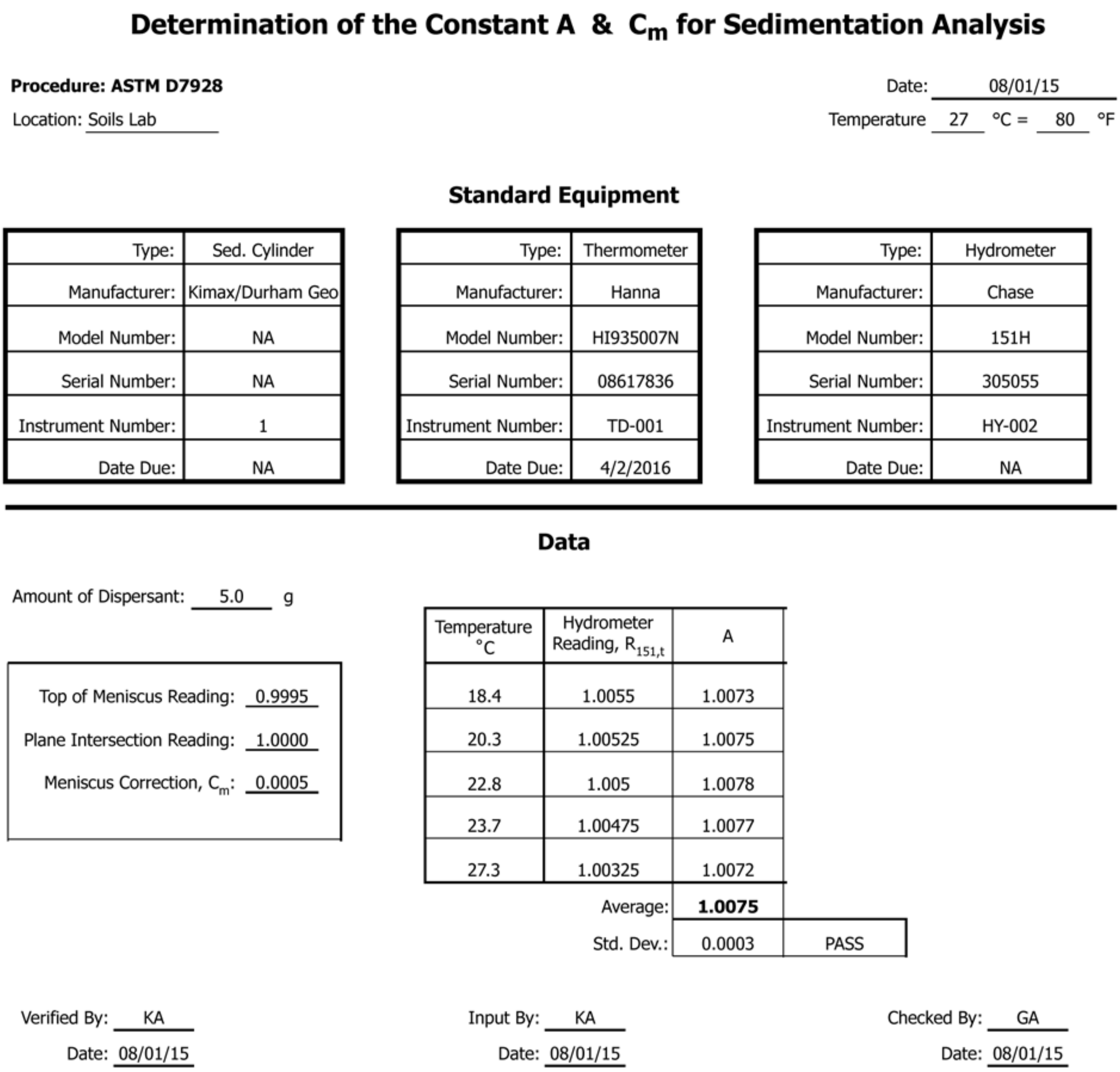
Checked By: KA
Date: 08/01/15

Input By: KA
Date: 08/01/15

Sticker Applied By: Not applicable
Date: –

Checked By: GA
Date: 08/01/15

FIG. X1.6 Example Sedimentation Cylinder Check—Adjustment



Determination of the Constant A & C_m for Sedimentation Analysis

Procedure: ASTM D7928

Date: 08/01/15

Location: Soils Lab

Temperature 27 °C = 80 °F

Standard Equipment

Type:	Sed. Cylinder
Manufacturer:	Kimax/Durham Geo
Model Number:	NA
Serial Number:	NA
Instrument Number:	1
Date Due:	NA

Type:	Thermometer
Manufacturer:	Hanna
Model Number:	HI935007N
Serial Number:	08617836
Instrument Number:	TD-001
Date Due:	4/2/2016

Type:	Hydrometer
Manufacturer:	Chase
Model Number:	151H
Serial Number:	305055
Instrument Number:	HY-002
Date Due:	NA

Data

Amount of Dispersant: 5.0 g

Top of Meniscus Reading: 0.9995

Plane Intersection Reading: 1.0000

Meniscus Correction, C_m: 0.0005

Temperature °C	Hydrometer Reading, $R_{151,t}$	A	
18.4	1.0055	1.0073	
20.3	1.00525	1.0075	
22.8	1.005	1.0078	
23.7	1.00475	1.0077	
27.3	1.00325	1.0072	
	Average:	**1.0075**	
	Std. Dev.:	0.0003	PASS

Verified By: KA
Date: 08/01/15

Input By: KA
Date: 08/01/15

Checked By: GA
Date: 08/01/15

FIG. X1.7 Example of Constant A and Meniscus Correction Determination

ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

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 International 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, at the address shown below.

Designation: D698 – 12$^{\varepsilon 2}$

Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3))[1]

This standard is issued under the fixed designation D698; 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 standard has been approved for use by agencies of the U.S. Department of Defense.

ε^1 NOTE—Editorial corrections made throughout in January 2014.
ε^2 NOTE—Editorially corrected variable for Eq A1.2 in July 2015.

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1. Scope*

1.1 These test methods cover laboratory compaction methods used to determine the relationship between molding water content and dry unit weight of soils (compaction curve) compacted in a 4 or 6-in. (101.6 or 152.4-mm) diameter mold with a 5.50-lbf (24.5-N) rammer dropped from a height of 12.0 in. (305 mm) producing a compactive effort of 12 400 ft-lbf/ft^3 (600 kN-m/m^3).

NOTE 1—The equipment and procedures are similar as those proposed by R. R. Proctor (*Engineering News Record*—September 7, 1933) with this one major exception: his rammer blows were applied as “12 inch firm strokes” instead of free fall, producing variable compactive effort depending on the operator, but probably in the range 15 000 to 25 000 ft-lbf/ft^3 (700 to 1200 kN-m/m^3). The standard effort test (see 3.1.4) is sometimes referred to as the Proctor Test.

1.1.1 Soils and soil-aggregate mixtures are to 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 gravel or crushed rock. Hereafter referred to as either soil or material.

1.2 These test methods apply only to soils (materials) that have 30 % or less by mass of particles retained on the ¾-in. (19.0-mm) sieve and have not been previously compacted in the laboratory; that is, do not reuse compacted soil.

1.2.1 For relationships between unit weights and molding water contents of soils with 30 % or less by mass of material retained on the ¾-in. (19.0-mm) sieve to unit weights and molding water contents of the fraction passing ¾-in. (19.0-mm) sieve, see Practice D4718.

1.3 Three alternative methods are provided. The method used shall be as indicated in the specification for the material being tested. If no method is specified, the choice should be based on the material gradation.

1.3.1 *Method A:*

1.3.1.1 *Mold*—4-in. (101.6-mm) diameter.

1.3.1.2 *Material*—Passing No. 4 (4.75-mm) sieve.

1.3.1.3 *Layers*—Three.

1.3.1.4 *Blows per Layer*—25.

1.3.1.5 *Usage*—May be used if 25 % or less (see 1.4) by mass of the material is retained on the No. 4 (4.75-mm) sieve.

1.3.1.6 *Other Usage*—If this gradation requirement cannot be met, then Method C may be used.

1.3.2 *Method B:*

1.3.2.1 *Mold*—4-in. (101.6-mm) diameter.

1.3.2.2 *Material*—Passing ⅜-in. (9.5-mm) sieve.

1.3.2.3 *Layers*—Three.

1.3.2.4 *Blows per Layer*—25.

1.3.2.5 *Usage*—May be used if 25 % or less (see 1.4) by mass of the material is retained on the ⅜-in. (9.5-mm) sieve.

1.3.2.6 *Other Usage*—If this gradation requirement cannot be met, then Method C may be used.

1.3.3 *Method C:*

1.3.3.1 *Mold*—6-in. (152.4-mm) diameter.

1.3.3.2 *Material*—Passing ¾-in. (19.0-mm) sieve.

1.3.3.3 *Layers*—Three.

1.3.3.4 *Blows per Layer*—56.

1.3.3.5 *Usage*—May be used if 30 % or less (see 1.4) by mass of the material is retained on the ¾-in. (19.0-mm) sieve.

1.3.4 The 6-in. (152.4-mm) diameter mold shall not be used with Method A or B.

NOTE 2—Results have been found to vary slightly when a material is tested at the same compactive effort in different size molds, with the smaller mold size typically yielding larger values of density/unit weight (**1**, pp. 21+).[2]

1.4 If the test specimen contains more than 5 % by mass of oversize fraction (coarse fraction) and the material will not be

***A Summary of Changes section appears at the end of this standard**

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[1] These Test Methods are under the jurisdiction of ASTM Committee D18 on Soil and Rock and are the direct responsibility of Subcommittee D18.03 on Texture, Plasticity and Density Characteristics of Soils.

Current edition approved May 1, 2012. Published June 2012. Originally approved in 1942. Last previous edition approved in 2000 as D698 – 07$^{\varepsilon 1}$. DOI: 10.1520/D0698-12E01.

[2] The boldface numbers in parentheses refer to the list of references at the end of this standard.

included in the test, corrections must be made to the unit mass and molding water content of the specimen or to the appropriate field-in-place density test specimen using Practice D4718.

1.5 This test method will generally produce a well-defined maximum dry unit weight for non-free draining soils. If this test method is used for free-draining soils the maximum unit weight may not be well defined, and can be less than obtained using Test Methods D4253.

1.6 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026, unless superseded by this standard.

1.6.1 For purposes of comparing measured or calculated value(s) with specified limits, the measured or calculated value(s) shall be rounded to the nearest decimal or significant digits in the specified limits.

1.6.2 The procedures used to specify how data are collected/recorded or calculated, in this standard are regarded as the industry standard. In addition, they are representative of the significant digits that generally should be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of this standard to consider significant digits used in analytical methods for engineering design.

1.7 The values in inch-pound units are to be regarded as the standard. The values stated in SI units are provided for information only, except for units of mass. The units for mass are given in SI units only, g or kg.

1.7.1 It is common practice in the engineering profession to concurrently use pounds to represent both a unit of mass (lbm) and a force (lbf). This implicitly combines two separate systems of units; that is, the absolute system and the gravitational system. It is scientifically undesirable to combine the use of two separate sets of inch-pound units within a single standard. This standard has been written using the gravitational system of units when dealing with the inch-pound system. In this system, the pound (lbf) represents a unit of force (weight). However, the use of balances or scales recording pounds of mass (lbm) or the recording of density in lbm/ft^3 shall not be regarded as a nonconformance with this standard.

1.8 *This standard does not purport to address all of the safety concerns, if any, 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.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

C127 Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregate
C136 Test Method for Sieve Analysis of Fine and Coarse Aggregates
D653 Terminology Relating to Soil, Rock, and Contained Fluids
D854 Test Methods for Specific Gravity of Soil Solids by Water Pycnometer
D2168 Practices for Calibration of Laboratory Mechanical-Rammer Soil Compactors
D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
D2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)
D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D4253 Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table
D4718 Practice for Correction of Unit Weight and Water Content for Soils Containing Oversize Particles
D4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing
D4914 Test Methods for Density of Soil and Rock in Place by the Sand Replacement Method in a Test Pit
D5030 Test Method for Density of Soil and Rock in Place by the Water Replacement Method in a Test Pit
D6026 Practice for Using Significant Digits in Geotechnical Data
D6913 Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis
E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves
E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
IEEE/ASTM SI 10 Standard for Use of the International System of Units (SI): the Modern Metric System

3. Terminology

3.1 *Definitions:*

3.1.1 See Terminology D653 for general definitions.

3.1.2 *molding water content, n*—the adjusted water content of a soil (material) that will be compacted/reconstituted.

3.1.3 *standard effort—in compaction testing*, the term for the 12 400 ft-lbf/ft^3 (600 kN-m/m^3) compactive effort applied by the equipment and methods of this test.

3.1.4 *standard maximum dry unit weight, $\gamma_{d,max}$ in lbf/ft^3 (kN/m^3)—in compaction testing*, the maximum value defined by the compaction curve for a compaction test using standard effort.

3.1.5 *standard optimum water content, w_{opt}* in %*—in compaction testing*, the molding water content at which a soil can be compacted to the maximum dry unit weight using standard compactive effort.

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[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *oversize fraction (coarse fraction), P_C in %*—the portion of total specimen not used in performing the compaction test; it may be the portion of total specimen retained on the No. 4 (4.75-mm) sieve in Method A, ⅜-in. (9.5-mm) sieve in Method B, or ¾-in. (19.0-mm) sieve in Method C.

3.2.2 *test fraction (finer fraction), P_F in %*—the portion of the total specimen used in performing the compaction test; it is the fraction passing the No. 4 (4.75-mm) sieve in Method A, passing the ⅜-in. (9.5-mm) sieve in Method B, or passing the ¾-in. (19.0-mm) sieve in Method C.

4. Summary of Test Method

4.1 A soil at a selected molding water content is placed in three layers into a mold of given dimensions, with each layer compacted by 25 or 56 blows of a 5.50-lbf (24.47-N) rammer dropped from a distance of 12.00 in. (304.8 mm), subjecting the soil to a total compactive effort of about 12 400 ft-lbf/ft^3 (600 kN-m/m^3). The resulting dry unit weight is determined. The procedure is repeated for a sufficient number of molding water contents to establish a relationship between the dry unit weight and the molding water content for the soil. This data, when plotted, represents a curvilinear relationship known as the compaction curve. The values of optimum water content and standard maximum dry unit weight are determined from the compaction curve.

5. Significance and Use

5.1 Soil placed as engineering fill (embankments, foundation pads, road bases) is compacted to a dense state to obtain satisfactory engineering properties such as, shear strength, compressibility, or permeability. In addition, foundation soils are often compacted to improve their engineering properties. Laboratory compaction tests provide the basis for determining the percent compaction and molding water content needed to achieve the required engineering properties, and for controlling construction to assure that the required compaction and water contents are achieved.

5.2 During design of an engineered fill, shear, consolidation, permeability, or other tests require preparation of test specimens by compacting at some molding water content to some unit weight. It is common practice to first determine the optimum water content (w_{opt}) and maximum dry unit weight ($\gamma_{d,max}$) by means of a compaction test. Test specimens are compacted at a selected molding water content (w), either wet or dry of optimum (w_{opt}) or at optimum (w_{opt}), and at a selected dry unit weight related to a percentage of maximum dry unit weight ($\gamma_{d,max}$). The selection of molding water content (w), either wet or dry of optimum (w_{opt}) or at optimum (w_{opt}) and the dry unit weight ($\gamma_{d,max}$) may be based on past experience, or a range of values may be investigated to determine the necessary percent of compaction.

5.3 Experience indicates that the methods outlined in 5.2 or the construction control aspects discussed in 5.1 are extremely difficult to implement or yield erroneous results when dealing with certain soils. 5.3.1 – 5.3.3 describe typical problem soils, the problems encountered when dealing with such soils and possible solutions for these problems.

5.3.1 *Oversize Fraction*—Soils containing more than 30 % oversize fraction (material retained on the ¾-in. (19-mm) sieve) are a problem. For such soils, there is no ASTM test method to control their compaction and very few laboratories are equipped to determine the laboratory maximum unit weight (density) of such soils (USDI Bureau of Reclamation, Denver, CO and U.S. Army Corps of Engineers, Vicksburg, MS). Although Test Methods D4914 and D5030 determine the "field" dry unit weight of such soils, they are difficult and expensive to perform.

5.3.1.1 One method to design and control the compaction of such soils is to use a test fill to determine the required degree of compaction and the method to obtain that compaction, followed by use of a method specification to control the compaction. Components of a method specification typically contain the type and size of compaction equipment to be used, the lift thickness, acceptable range in molding water content, and the number of passes.

NOTE 3—Success in executing the compaction control of an earthwork project, especially when a method specification is used, is highly dependent upon the quality and experience of the contractor and inspector.

5.3.1.2 Another method is to apply the use of density correction factors developed by the USDI Bureau of Reclamation (**2, 3**) and U.S. Corps of Engineers (**4**). These correction factors may be applied for soils containing up to about 50 to 70 % oversize fraction. Each agency uses a different term for these density correction factors. The USDI Bureau of Reclamation uses *D* ratio (or *D*–VALUE), while the U.S. Corps of Engineers uses Density Interference Coefficient (I_c).

5.3.1.3 The use of the replacement technique (Test Method D698–78, Method D), in which the oversize fraction is replaced with a finer fraction, is inappropriate to determine the maximum dry unit weight, $\gamma_{d,max}$, of soils containing oversize fractions (**4**).

5.3.2 *Degradation*—Soils containing particles that degrade during compaction are a problem, especially when more degradation occurs during laboratory compaction than field compaction, as is typical. Degradation typically occurs during the compaction of a granular-residual soil or aggregate. When degradation occurs, the maximum dry-unit weight increases (**1**, p. 73) so that the laboratory maximum value is not representative of field conditions. Often, in these cases, the maximum dry unit weight is impossible to achieve in the field.

5.3.2.1 Again, for soils subject to degradation, the use of test fills and method specifications may help. Use of replacement techniques is not correct.

5.3.3 *Gap Graded*—Gap-graded soils (soils containing many large particles with limited small particles) are a problem because the compacted soil will have larger voids than usual. To handle these large voids, standard test methods (laboratory or field) typically have to be modified using engineering judgement.

NOTE 4—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/inspection, and the like. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors;

Practice D3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *Mold Assembly*—The molds shall be cylindrical in shape, made of rigid metal and be within the capacity and dimensions indicated in 6.1.1 or 6.1.2 and Figs. 1 and 2. See also Table 1. The walls of the mold may be solid, split, or tapered. The "split" type may consist 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 "tapered" type shall have an internal diameter taper that is uniform and not more than 0.200 in./ft (16.7 mm/m) of mold height. Each mold shall have a base plate and an extension collar assembly, both made of rigid metal and constructed so they can be securely attached and easily detached from the mold. The extension collar assembly shall have a height extending above the top of the mold of at least 2.0 in. (51 mm) which may include an upper section that flares out to form a funnel, provided there is at least a 0.75 in. (19 mm) straight cylindrical section beneath it. The extension collar shall align with the inside of the mold. The bottom of the base plate and bottom of the centrally recessed area that accepts the cylindrical mold shall be planar within ±0.005 in. (±0.1 mm).

6.1.1 *Mold, 4 in.*—A mold having a 4.000 ± 0.016-in. (101.6 ± 0.4-mm) average inside diameter, a height of 4.584 ± 0.018 in. (116.4 ± 0.5 mm) and a volume of 0.0333 ± 0.0005 ft^3 (943.0 ± 14 cm^3). A mold assembly having the minimum required features is shown in Fig. 1.

6.1.2 *Mold, 6 in.*—A mold having a 6.000 ± 0.026-in. (152.4 ± 0.7-mm) average inside diameter, a height of 4.584 ± 0.018 in. (116.4 ± 0.5 mm), and a volume of 0.0750 ± 0.0009 ft^3 (2124 ± 25 cm^3). A mold assembly having the minimum required features is shown in Fig. 2.

6.2 *Rammer*—A rammer, either manually operated as described further in 6.2.1 or mechanically operated as described in 6.2.2. The rammer shall fall freely through a distance of 12.00 ± 0.05 in. (304.8 ± 1 mm) from the surface of the specimen. The weight of the rammer shall be 5.50 ± 0.02 lbf (24.47 ± 0.09 N, or mass of 2.495 ± 0.009 kg), except that the weight of the mechanical rammers may be adjusted as described in Practices D2168; see Note 5. The striking face of the rammer shall be planar and circular, except as noted in 6.2.2.1, with a diameter when new of 2.000 ± 0.005 in. (50.80 ± 0.13 mm). The rammer shall be replaced if the striking face becomes worn or bellied to the extent that the diameter exceeds 2.000 ± 0.01 in. (50.80 ± 0.25 mm).

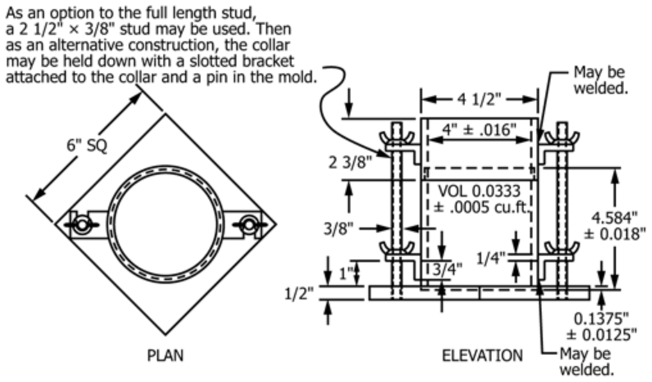

FIG. 1 4.0-in. Cylindrical Mold

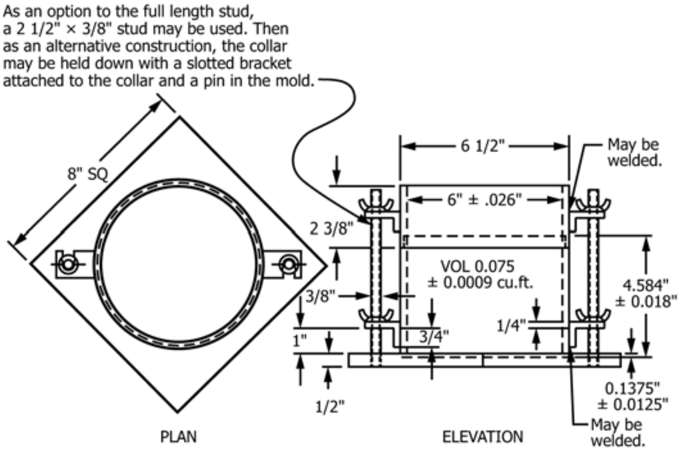

FIG. 2 6.0-in. Cylindrical Mold

TABLE 1 Metric Equivalents for Figs. 1 and 2

in.	mm
0.016	0.41
0.026	0.66
0.032	0.81
0.028	0.71
½	12.70
2½	63.50
2⅝	66.70
4	101.60
4½	114.30
4.584	116.43
4¾	120.60
6	152.40
6½	165.10
6⅝	168.30
6¾	171.40
8¼	209.60
ft^3	cm^3
1⁄30 (0.0333)	943
0.0005	14
(0.0750)	2,124
0.0011	31

NOTE 5—It is a common and acceptable practice to determine the weight of the rammer using either a kilogram or pound balance and assume 1 lbf is equivalent to 0.4536 kg, 1 lbf is equivalent to 1 lbm, or 1 N is equivalent to 0.2248 lbf or 0.1020 kg.

6.2.1 *Manual Rammer*—The rammer shall be equipped with a guide sleeve that has sufficient clearance that the free fall of the rammer shaft and head is not restricted. The guide sleeve shall have at least four vent holes at each end (eight holes total) located with centers ¾ ± 1⁄16 in. (19 ± 2 mm) from each end and spaced 90 degrees apart. The minimum diameter of the vent holes shall be ⅜ in. (9.5 mm). Additional holes or slots may be incorporated in the guide sleeve.

6.2.2 *Mechanical Rammer-Circular Face*—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. The mechanical rammer shall meet the standardization/calibration requirements of Practices D2168. The mechanical rammer shall be equipped with a positive mechanical means to support the rammer when not in operation.

6.2.2.1 *Mechanical Rammer-Sector Face*—The sector face can be used with the 6-in. (152.4-mm) mold, as an alternative to the circular face mechanical rammer described in 6.2.2. The striking face shall have the shape of a sector of a circle of radius equal to 2.90 ± 0.02 in. (73.7 ± 0.5 mm) and an area about the same as the circular face, see 6.2. The rammer shall operate in such a manner that the vertex of the sector is positioned at the center of the specimen and follow the compaction pattern given in Fig. 3b.

6.3 *Sample Extruder (optional)*—A jack, with frame or other device adapted for the purpose of extruding compacted specimens from the mold.

6.4 *Balance*—A Class GP5 balance meeting the requirements of Guide D4753 for a balance of 1-g readability. If the water content of the compacted specimens is determined using a representative portion of the specimen, rather than the whole specimen, and if the representative portion is less than 1000 g, a Class GP2 balance having a 0.1-g readability is needed in order to comply with Test Methods D2216 requirements for determining water content to 0.1 %.

NOTE 6—Use of a balance having an equivalent capacity and a readability of 0.002 lbm as an alternative to a class GP5 balance should not be regarded as nonconformance to this standard.

6.5 *Drying Oven*—Thermostatically controlled oven, capable of maintaining a uniform temperature of 230 ± 9°F (110 ± 5°C) throughout the drying chamber. These requirements typically require the use of a forced-draft type oven. Preferably the oven should be vented outside the building.

6.6 *Straightedge*—A stiff metal straightedge of any convenient length but not less than 10 in. (250 mm). The total length of the straightedge shall be machined straight to a tolerance of ±0.005 in. (±0.1 mm). The scraping edge shall be beveled if it is thicker than ⅛ in. (3 mm).

6.7 *Sieves*—¾ in. (19.0 mm), ⅜ in. (9.5 mm), and No. 4 (4.75 mm), conforming to the requirements of Specification E11.

6.8 *Mixing Tools*—Miscellaneous tools such as mixing pan, spoon, trowel, spatula, spraying device (to add water evenly), and (preferably, but optional) suitable mechanical device for thoroughly mixing the subspecimen of soil with increments of water.

7. Standardization/Calibration

7.1 Perform standardizations before initial use, after repairs or other occurrences that might affect the test results, at intervals not exceeding 1,000 test specimens, or annually, whichever occurs first, for the following apparatus:

7.1.1 *Balance*—Evaluate in accordance with Guide D4753.

7.1.2 *Molds*—Determine the volume as described in Annex A1.

7.1.3 *Manual Rammer*—Verify the free fall distance, rammer weight, and rammer face are in accordance with 6.2. Verify the guide sleeve requirements are in accordance with 6.2.1.

7.1.4 *Mechanical Rammer*—Verify and adjust if necessary that the mechanical rammer is in accordance with Practices D2168. In addition, the clearance between the rammer and the inside surface of the mold shall be verified in accordance with 6.2.2.

8. Test Specimen

8.1 The minimum specimen (test fraction) mass for Methods A and B is about 16 kg, and for Method C is about 29 kg of dry soil. Therefore, the field sample should have a moist mass of at least 23 kg and 45 kg, respectively. Greater masses would be required if the oversize fraction is large (see 10.2 or 10.3) or an additional molding water content is taken during compaction of each point (see 10.4.2.1).

8.2 If gradation data is not available, estimate the percentage of material (by mass) retained on the No. 4 (4.75-mm), ⅜-in. (9.5-mm), or ¾-in. (19.0-mm) sieve as appropriate for selecting Method A, B, or C, respectively. If it appears the percentage retained of interest is close to the allowable value for a given Method (A, B, or C), then either:

8.2.1 Select a Method that allows a higher percentage retained (B or C).

8.2.2 Using the Method of interest, process the specimen in accordance with 10.2 or 10.3, this determines the percentage retained for that method. If acceptable, proceed, if not go to the next Method (B or C).

8.2.3 Determine percentage retained values by using a representative portion from the total sample, and performing a simplified or complete gradation analysis using the sieve(s) of

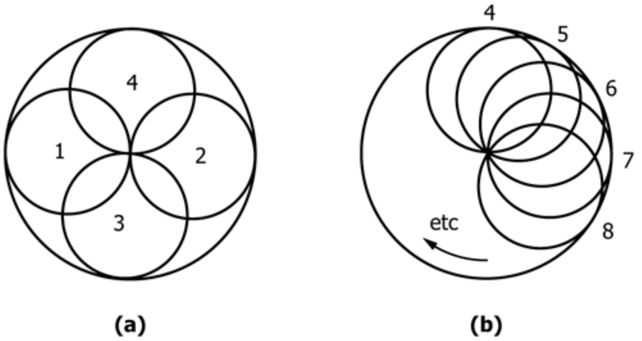

FIG. 3 Rammer Pattern for Compaction in 4 in. (101.6 mm) Mold

interest and Test Methods D6913 or C136. It is only necessary to calculate the retained percentage(s) for the sieve or sieves for which information is desired.

9. Preparation of Apparatus

9.1 Select the proper compaction mold(s), collar, and base plate in accordance with the Method (A, B, or C) being used. Check that its volume is known and determined with or without base plate, free of nicks or dents, and will fit together properly.

NOTE 7—Mass requirements are given in 10.4.

9.2 Check that the manual or mechanical rammer assembly is in good working condition and that parts are not loose or worn. Make any necessary adjustments or repairs. If adjustments or repairs are made, the rammer must be re-standardized.

10. Procedure

10.1 *Soils:*

10.1.1 Do not reuse soil that has been previously compacted in the laboratory. The reuse of previously compacted soil yields a significantly greater maximum dry unit weight (**1**, p. 31).

10.1.2 When using this test method for soils containing hydrated halloysite, or in which past experience indicates that results will be altered by air-drying, use the moist preparation method (see 10.2). In referee testing, each laboratory has to use the same method of preparation, either moist (preferred) or air-dried.

10.1.3 Prepare the soil specimens for testing in accordance with 10.2 (preferred) or with 10.3.

10.2 *Moist Preparation Method (preferred)*—Without previously drying the sample/specimen, process it over a No. 4 (4.75-mm), ⅜-in. (9.5-mm), or ¾-in. (19.0-mm) sieve, depending on the Method (A, B, or C) being used or required as covered in 8.2. For additional processing details, see Test Methods D6913. Determine and record the mass of both the retained and passing portions (oversize fraction and test fraction, respectively) to the nearest g. Oven dry the oversize fraction and determine and record its dry mass to the nearest g. If it appears more than 0.5 % of the total dry mass of the specimen is adhering to the oversize fraction, wash that fraction. Then determine and record its oven dry mass to the nearest g. Determine and record the water content of the processed soil (test fraction). Using that water content, determine and record the oven dry mass of the test fraction to the nearest g. Based on these oven dry masses, the percent oversize fraction, P_C, and test fraction, P_F, shall be determined and recorded, unless a gradation analysis has already been performed, see Section 11 on Calculations.

10.2.1 From the test fraction, select and prepare at least four (preferably five) subspecimens having molding water contents such that they bracket the estimated optimum water content. A subspecimen having a molding water content close to optimum should be prepared first by trial additions or removals of water and mixing (see Note 8). Select molding water contents for the rest of the subspecimens to provide at least two subspecimens wet and two subspecimens dry of optimum, and molding water contents varying by about 2 %. At least two molding water contents are necessary on the wet and dry side of optimum to define the dry-unit-weight compaction curve (see 10.5). Some soils with very high optimum water content or a relatively flat compaction curve may require larger molding water content increments to obtain a well-defined maximum dry unit weight. Molding water content increments should not exceed about 4 %.

NOTE 8—With practice it is usually possible to visually judge a point near optimum water content. Typically, cohesive soils at the optimum water content can be squeezed into a lump that sticks together when hand pressure is released, but will break cleanly into two sections when "bent." They tend to crumble at molding water contents dry of optimum; while, they tend to stick together in a sticky cohesive mass wet of optimum. The optimum water content is typically slightly less than the plastic limit. While for cohesionless soils, the optimum water content is typically close to zero or at the point where bleeding occurs.

10.2.2 Thoroughly mix the test fraction, then using a scoop select representative soil for each subspecimen (compaction point). Select about 2.3 kg when using Method A or B, or about 5.9 kg for Method C. Test Methods D6913 section on Specimen and Annex A2 gives additional details on obtaining representative soil using this procedure and why it is the preferred method. To obtain the subspecimen's molding water contents selected in 10.2.1, add or remove the required amounts of water as follows. To add water, spray it into the soil during mixing; to remove water, allow the soil to dry in air at ambient temperature or in a drying apparatus such that the temperature of the sample does not exceed 140°F (60°C). Mix the soil frequently during drying to facilitate an even water content distribution. Thoroughly mix each subspecimen to facilitate even distribution of water throughout and then place in a separate covered container to stand (cure) in accordance with Table 2 prior to compaction. For selecting a standing time, the soil may be classified using Practice D2487, Practice D2488, or data on other samples from the same material source. For referee testing, classification shall be by Practice D2487.

10.3 *Dry Preparation Method*—If the sample/specimen is too damp to be friable, reduce the water content by air drying until the material is friable. Drying may be in air or by the use of drying apparatus such that the temperature of the sample does not exceed 140°F (60°C). Thoroughly break up the aggregations in such a manner as to avoid breaking individual particles. Process the material over the appropriate sieve: No. 4 (4.75-mm), ⅜-in. (9.5-mm), or ¾-in. (19.0-mm). When preparing the material by passing over the ¾-in. sieve for compaction in the 6-in. mold, break up aggregations sufficiently to at least pass the ⅜-in. sieve in order to facilitate the distribution of water throughout the soil in later mixing. Determine and record the water content of the test fraction and all masses covered in 10.2, as applicable to determine the percent oversize fraction, P_C, and test fraction, P_F.

10.3.1 From the test fraction, select and prepare at least four (preferably five) subspecimens in accordance with 10.2.1 and

TABLE 2 Required Standing Times of Moisturized Specimens

Classification	Minimum Standing Time, h
GW, GP, SW, SP	No Requirement
GM, SM	3
All other soils	16

10.2.2, except for the following: Use either a mechanical splitting or quartering process to obtain the subspecimens. As stated in Test Methods D6913, both of these processes will yield non-uniform subspecimens compared to the moist procedure. Typically, only the addition of water to each subspecimen will be required.

10.4 *Compaction*—After standing (curing), if required, each subspecimen (compaction point) shall be compacted as follows:

10.4.1 Determine and record the mass of the mold or mold and base plate, see 10.4.7.

10.4.2 Assemble and secure the mold and collar to the base plate. Check the alignment of the inner wall of the mold and mold extension collar. Adjust if necessary. The mold shall rest, without wobbling/rocking on a uniform rigid foundation, such as provided by a cylinder or cube of concrete with a weight or mass of not less than 200-lbf or 91-kg, respectively. Secure the base plate to the rigid foundation. The method of attachment to the rigid foundation shall allow easy removal of the assembled mold, collar and base plate after compaction is completed.

10.4.2.1 During compaction, it is advantageous but not required to determine the water content of each subspecimen. This provides a check on the molding water content determined for each compaction point and the magnitude of bleeding, see 10.4.9. However, more soil will have to be selected for each subspecimen than stated in 10.2.2.

10.4.3 Compact the soil in three layers. After compaction, each layer should be approximately equal in thickness and extend into the collar. Prior to compaction, place the loose soil into the mold and spread into a layer of uniform thickness. Lightly tamp the soil prior to compaction until it is not in a fluffy or loose state, using either the manual rammer or a 2±-in. (50±-mm) diameter cylinder. Following compaction of each of the first two layers, any soil that has not been compacted; such as adjacent to the mold walls or extends above the compacted surface (up the mold walls) shall be trimmed. The trimmed soil shall be discarded. A knife or other suitable device may be used. The total amount of soil used shall be such that the third compacted layer slightly extends into the collar, but does not extend more than approximately ¼-in. (6-mm) above the top of the mold. If the third layer does extend above this limit, then the compaction point shall be discarded. In addition, the compaction point shall be discarded when the last blow on the rammer for the third layer results in the bottom of the rammer extending below the top of the compaction mold; unless the soil is pliable enough, that this surface can easily be forced above the top of the compaction mold during trimming (see Note 9).

10.4.4 Compact each layer with 25 blows for the 4-in. (101.6-mm) mold or with 56 blows for the 6-in. (152.4-mm) mold. The manual rammer shall be used for referee testing.

10.4.5 In operating the manual rammer, take care to avoid lifting the guide sleeve during the rammer upstroke. Hold the guide sleeve steady and within 5° of vertical. Apply the blows at a uniform rate of about 25 blows/min and in such a manner as to provide complete, uniform coverage of the specimen surface. When using a 4-in. (101.6-mm) mold and manual rammer, follow the blow pattern given in Fig. 3a and Fig. 3b; while for a mechanical rammer, follow the pattern in Fig. 3b. When using a 6-in. (152.4-mm) mold and manual rammer, follow the blow pattern given in Fig. 4 up to the 9th blow, then systematically around the mold (Fig. 3b) and in the middle. When using a 6-in. (152.4-mm) mold and a mechanical rammer equipped with a sector face, the mechanical rammer shall be designed to follow the compaction pattern given in Fig. 3b. When using a 6-in. (152.4-mm) mold and a mechanical rammer equipped with a circular face, the mechanical rammer shall be designed to distribute the blows uniformly over the

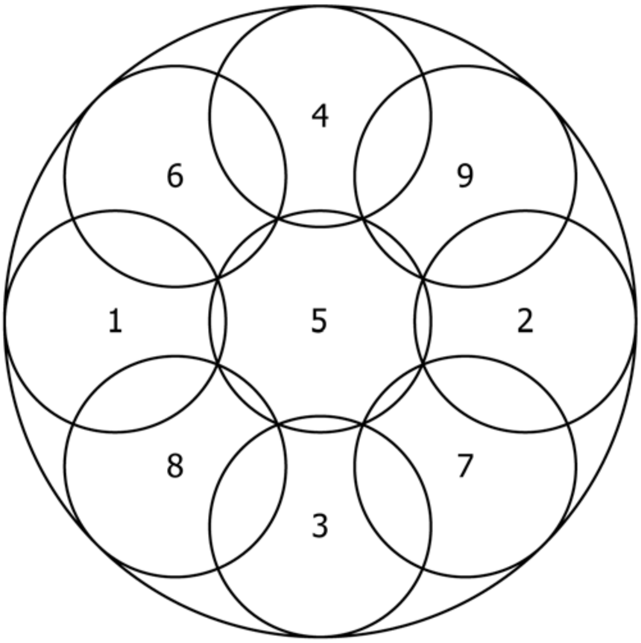

FIG. 4 Rammer Pattern for Compaction in 6 in. (152.4 mm) Mold

surface of the specimen. If the surface of the compacted soil becomes highly uneven (see Note 9), then adjust the pattern to follow the logic given in Fig. 3a or Fig. 4. This will most likely void the use of a mechanical rammer for such compaction points.

NOTE 9—When compacting specimens wetter than optimum water content, uneven compacted surfaces can occur and operator judgement is required as to the average height of the specimen and rammer pattern during compaction.

10.4.6 Following compaction of the last layer, remove the collar and base plate (except as noted in 10.4.7) from the mold. A knife may be used to trim the soil adjacent to the collar to loosen the soil from the collar before removal to avoid disrupting the soil below the top of the mold. In addition, to prevent/reduce soil sticking to the collar or base plate, rotate them before removal.

10.4.7 Carefully trim the compacted specimen even with the top of the mold by means of the straightedge scraped across the top of the mold to form a plane surface even with the top of the mold. Initial trimming of the specimen above the top of the mold with a knife may prevent the soil from tearing below the top of the mold. Fill any holes in the top surface with unused or trimmed soil from the specimen, press in with the fingers, and again scrape the straightedge across the top of the mold. If gravel size particles are encountered, trim around them or remove them, whichever is the easiest and reduces the disturbance of the compacted soil. The estimated volume of particles above the surface of the compacted soil and holes in that surface shall be equal, fill in remaining holes as mentioned above. Repeat the appropriate preceding operations on the bottom of the specimen when the mold volume was determined without the base plate. For very wet or dry soils, soil or water may be lost if the base plate is removed. For these situations, leave the base plate attached to the mold. When the base plate is left attached, the volume of the mold must be calibrated with the base plate attached to the mold rather than a plastic or glass plate as noted in Annex A1, A1.4.

10.4.8 Determine and record the mass of the specimen and mold to the nearest g. When the base plate is left attached, determine and record the mass of the specimen, mold and base plate to the nearest g.

10.4.9 Remove the material from the mold. Obtain a specimen for molding water content by using either the whole specimen (preferred method) or a representative portion. When the entire specimen is used, break it up to facilitate drying. Otherwise, obtain a representative portion of the three layers, removing enough material from the specimen to report the water content to 0.1 %. The mass of the representative portion of soil shall conform to the requirements of Table 1, Method B, of Test Methods D2216. Determine the molding water content in accordance with Test Methods D2216.

10.5 Following compaction of the last specimen, compare the wet unit weights to ensure that a desired pattern of obtaining data on each side of the optimum water content will be attained for the dry-unit-weight compaction curve. Plotting the wet unit weight and molding water content of each compacted specimen can be an aid in making the above evaluation. If the desired pattern is not obtained, additional compacted specimens will be required. Generally, for experienced plotters of compaction curves, one compaction point wet of the optimum water content is adequate to define the maximum wet unit weight, see 11.2.

11. Calculations and Plotting (Compaction Curve)

11.1 *Fraction Percentages*—If gradation data from Test Methods D6913 is not available, calculate the dry mass of the test fraction, percentage of oversize fraction and test fraction as covered below and using the data from 10.2 or 10.3:

11.1.1 *Test Fraction*—Determine the dry mass of the test fraction as follows:

$$M_{d,tf} = \frac{M_{m,tf}}{1 + \frac{w_{tf}}{100}} \tag{1}$$

where:

$M_{d,tf}$ = dry mass of test fraction, nearest g or 0.001 kg,
$M_{m,tf}$ = moist mass of test fraction, nearest g or 0.001 kg, and
w_{tf} = water content of test fraction, nearest 0.1 %.

11.1.2 *Oversize Fraction Percentage*—Determine the oversize (coarse) fraction percentage as follows:

$$P_C = \frac{M_{d,of}}{M_{d,of} + M_{d,tf}} \tag{2}$$

where:

P_C = percentage of oversize (coarse) fraction, nearest %, and
$M_{d,of}$ = dry mass of oversize fraction, nearest g or 0.001 kg,

11.1.3 *Test Fraction Percentage*—Determine the test (finer) fraction percentage as follows:

$$P_F = 100 - P_C \tag{3}$$

where:

P_F = percentage of test (finer) fraction, nearest %.

11.2 *Density and Unit Weight*—Calculate the molding water content, moist density, dry density, and dry unit weight of each compacted specimen as explained below.

11.2.1 *Molding Water Content, w*—Calculate in accordance with Test Methods D2216 to nearest 0.1 %.

11.2.2 *Density and Unit Weights*—Calculate the moist (total) density (Eq 4), the dry density (Eq 5), and then the dry unit weight (Eq 6) as follows:

11.2.2.1 *Moist Density:*

$$\rho_m = K \times \frac{(M_t - M_{md})}{V} \tag{4}$$

where:

ρ_m = moist density of compacted subspecimen (compaction point), four significant digits, g/cm^3 or kg/m^3,
M_t = mass of moist soil in mold and mold, nearest g,
M_{md} = mass of compaction mold, nearest g,
V = volume of compaction mold, cm^3 or m^3 (see Annex A1), and

K = conversion constant, depending on density units and volume units.
Use 1 for g/cm^3 and volume in cm^3.
Use 1000 for g/cm^3 and volume in m^3.
Use 0.001 for kg/cm^3 and volume in m^3.
Use 1000 for kg/m^3 and volume in cm^3.

11.2.2.2 *Dry Density:*

$$\rho_d = \frac{\rho_m}{1 + \frac{w}{100}} \tag{5}$$

where:

ρ_d = dry density of compaction point, four significant digits, g/cm^3 or kg/m^3, and
w = molding water content of compaction point, nearest 0.1 %.

11.2.2.3 *Dry Unit Weight:*

$$\gamma_d = K_1 \times \rho_d \text{ in lbf/ft}^3 \tag{6}$$

or

$$\gamma_d = K_2 \times \rho_d \text{ in kN/m}^3 \tag{7}$$

where:

γ_d = dry unit weight of compacted specimen, four significant digits, in lbf/ft^3 or kN/m^3,
K_1 = conversion constant, depending on density units,
Use 62.428 for density in g/cm^3, or
Use 0.062428 for density in kg/m^3,
K_2 = conversion constant, depending on density units,
Use 9.8066 for density in g/cm^3, or
Use 0.0098066 for density in kg/m^3.

11.3 *Compaction Curve*—Plot the dry unit weight and molding water content values, the saturation curve (see 11.3.2), and draw the compaction curve as a smooth curve through the points (see example, Fig. 5). For each point on the compaction curve, calculate, record, and plot dry unit weight to the nearest 0.1 lbf/ft^3 (0.02 kN/m^3) and molding water content to the nearest 0.1 %. From the compaction curve, determine the compaction results: optimum water content, to nearest 0.1 % and maximum dry unit weight, to the nearest 0.1 lbf/ft^3 (0.02 kN/m^3). If more than 5 % by mass of oversize material was removed from the sample/specimen, calculate the corrected optimum water content and maximum dry unit weight of the total material using Practice D4718. This correction may be made to the appropriate field in-place density test specimen rather than to the laboratory compaction results.

11.3.1 In these plots, the scale sensitivities should remain the same, that is the change in molding water content or dry unit weight per division is constant between plots. Typically, the change in dry unit weight per division is twice that of molding water content's (2 lbf/ft^3 to 1 % w per major division). Therefore, any change in the shape of the compaction curve is a result of testing different material, not the plotting scale. However, a one to one ratio should be used for soils that have a relatively flat compaction curve (see 10.2.1), such as highly plastic soils or relatively free draining ones up to the point of bleeding.

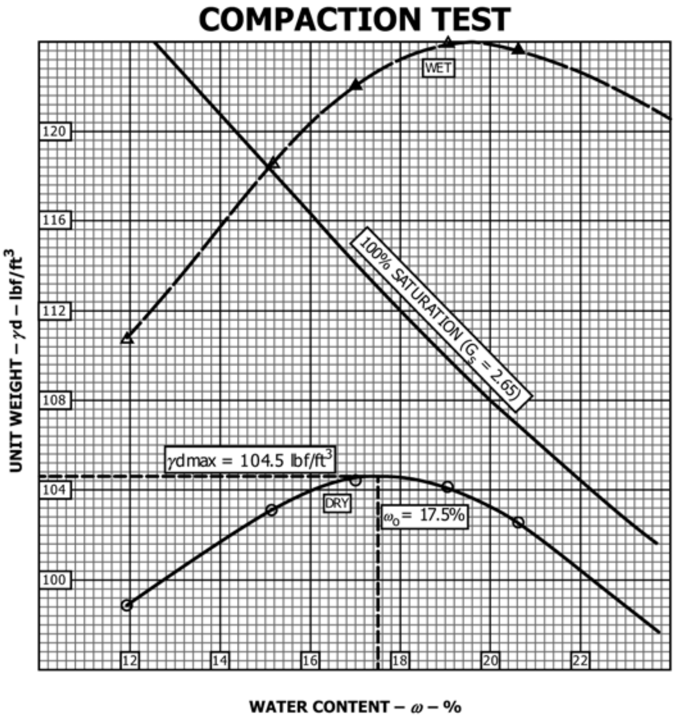

FIG. 5 Example Compaction Curve Plotting

11.3.1.1 The shape of the compaction curve on the wet side on optimum should typically follow that of the saturation curve. The shape of the compaction curve on the dry side of optimum may be relatively flat or up and down when testing some soils, such as relatively free draining ones or plastic soils prepared using the moist procedure and having molding water contents close to or less than the shrinkage limit.

11.3.2 Plot the 100 % saturation curve, based on either an estimated or a measured specific gravity. Values of water content for the condition of 100 % saturation can be calculated as explained in 11.4 (see example, Fig. 5).

NOTE 10—The 100 % saturation curve is an aid in drawing the compaction curve. For soils containing more than about 10 % fines and molding water contents well above optimum, the two curves generally become roughly parallel with the wet side of the compaction curve between 92 to 95 % saturation. Theoretically, the compaction curve cannot plot to the right of the 100 % saturation curve. If it does, there is an error in specific gravity, in measurements, in calculations, in testing, or in plotting. The 100 % saturation curve is sometimes referred to as the zero air voids curve or the complete saturation curve.

11.4 *Saturation Points*—To calculate points for plotting the 100 % saturation curve or zero air voids curve, select values of dry unit weight, calculate corresponding values of water content corresponding to the condition of 100 % saturation as follows:

$$w_{sat} = \frac{(\gamma_w)(G_s) - \gamma_d}{(\gamma_d)(G_s)} \times 100 \tag{8}$$

where:

w_{sat} = water content for complete saturation, nearest 0.1 %,
γ_w = unit weight of water, 62.32 lbf/ft ^{3} (9.789 kN/m^3) at 20°C,

γ_d = dry unit weight of soil, lbf/ft^3 (kN/m^3), three significant digits, and

G_s = specific gravity of soil (estimated or measured), to nearest 0.01 value, see 11.4.1.

11.4.1 Specific gravity may be estimated for the test fraction based on test data from other soils having the same soil classification and source or experience. Otherwise, a specific gravity test (Test Methods C127 or D854, or both) is necessary.

12. Report: Data Sheet(s)/Form(s)

12.1 The methodology used to specify how data are recorded on the test data sheet(s)/form(s), as described below, is covered in 1.6.

12.2 The data sheet(s)/form(s) shall contain as a minimum the following information:

12.2.1 Method used (A, B, or C).

12.2.2 Preparation method used (moist or dry).

12.2.3 As received water content if determined, nearest 1 %.

12.2.4 Standard optimum water content, Std-w_{opt} to nearest 0.1 %.

12.2.5 Standard maximum dry unit weight, Std-$\gamma_{d,max}$ nearest 0.1 lbf/ft^3 or 0.02 kN/m^3.

12.2.6 Type of rammer (manual or mechanical).

12.2.7 Soil sieve data when applicable for selection of Method (A, B, or C) used.

12.2.8 Description of sample used in test (as a minimum, color and group name and symbol), by Practice D2488, or classification by Practice D2487.

12.2.9 Specific gravity and method of determination, nearest 0.01 value.

12.2.10 Identification of sample used in test; for example, project number/name, location, depth, and the like.

12.2.11 Compaction curve plot showing compaction points used to establish compaction curve, and 100 % saturation curve, value or point of maximum dry unit weight and optimum water content.

12.2.12 Percentages for the fractions retained (P_C) and passing (P_F) the sieve used in Method A, B, or C, nearest 1 %. In addition, if compaction data (Std-w_{opt} and Std-$\gamma_{d,max}$) are corrected for the oversize fraction, include that data.

13. Precision and Bias

13.1 *Precision*—Criteria for judging the acceptability of test results obtained by these test methods on a range of soil types are given in Tables 3 and 4. These estimates of precision are based on the results of the interlaboratory program conducted by the ASTM Reference Soils and Testing Program.[4] In this program, Method A and the Dry Preparation Method were used. In addition, some laboratories performed three replicate tests per soil type (triplicate test laboratory), while other laboratories performed a single test per soil type (single test laboratory). A description of the soils tested is given in 13.1.4. The precision estimates vary with soil type, and may vary with methods used (Method A, B, or C, or wet/dry preparation method). Judgement is required when applying these estimates to another soil, method, or preparation method.

TABLE 3 Summary of Test Results from Triplicate Test Laboratories (Standard Effort Compaction)

(1) Number of Triplicate Test Labs			(2) Test Value^A (Units)	(3) Average Value^B			(4) Standard Deviation^C			(5) Acceptable Range of Two Results^{D,E}		
Soil Type:												
CH	CL	ML		CH	CL	ML	CH	CL	ML	CH	CL	ML
Single-Operator Results (Within-Laboratory Repeatability):												
11	12	11	$\gamma_{d,max}$ (pcf)	97.2	109.2	106.3	0.5	0.4	0.5	1.3	1.2	1.3
11	12	11	w_{opt} (%)	22.8	16.6	17.1	0.2	0.3	0.3	0.7	0.9	0.9
Multilaboratory Results (Between-Laboratory Reproducibility):												
11	12	11	$\gamma_{d,\ max}$ (pcf)	97.2	109.2	106.3	1.4	0.8	0.6	3.9	2.3	1.6
11	12	11	w_{opt} (%)	22.8	16.6	17.1	0.7	0.5	0.5	1.8	1.5	1.3

[A] $\gamma_{d,max}$(pcf) = standard maximum dry unit weight in lbf/ft^3 and w_{opt}(%) = standard optimum water in percent.

[B] The number of significant digits and decimal places presented are representative of the input data. In accordance with Practice D6026, the standard deviation and acceptable range of results can not have more decimal places than the input data.

[C] Standard deviation is calculated in accordance with Practice E691 and is referred to as the 1 s limit.

[D] Acceptable range of two results is referred to as the d2*s* limit. It is calculated as $1.960\sqrt{2}\cdot 1s$, as defined by Practice E177. The difference between two properly conducted tests should not exceed this limit. The number of significant digits/decimal places presented is equal to that prescribed by this standard or Practice D6026. In addition, the value presented can have the same number of decimal places as the standard deviation, even if that result has more significant digits than the standard deviation.

[E] Both values of $\gamma_{d,max}$ and w_{opt} have to fall within values given for the selected soil type.

TABLE 4 Summary of Single Test Results from Each Laboratories (Standard Effort Compaction)^A

(1) Number of Test Laboratories			(2) Test Value (Units)	(3) Average Value			(4) Standard Deviation			(5) Acceptable Range of Two Results		
Soil Type:												
CH	CL	ML		CH	CL	ML	CH	CL	ML	CH	CL	ML
Multilaboratory Results (Between-Laboratory Reproducibility):												
26	26	25	$\gamma_{d,max}$ (pcf)	97.3	109.2	106.2	1.6	1.1	1.0	4.5	3.0	2.9
			w_{opt} (%)	22.6	16.4	16.7	0.9	0.7	1.0	2.4	1.8	2.9

[A] See footnotes in Table 3.

13.1.1 The data in Table 3 are based on three replicate tests performed by each triplicate test laboratory on each soil type. The single operator and multilaboratory standard deviation show in Table 3, Column 4 were obtained in accordance with Practice E691, which recommends each testing laboratory perform a minimum of three replicate tests. Results of two properly conducted tests performed by the same operator on the same material, using the same equipment, and in the shortest practical period of time should not differ by more than the single-operator d2*s* shown in Table 3, Column 5. For definition of d2*s*, see footnote D in Table 1. Results of two properly conducted tests performed by different operators and on different days should not differ by more than the multilaboratory d2*s* limits shown in Table 3, Column 5.

13.1.2 In the ASTM Reference Soils and Testing Program, many of the laboratories performed only a single test on each

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[4] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D18-1008. Contact ASTM Customer Service at service@astm.org.

soil type. This is common practice in the design and construction industry. The data for each soil type in Table 4 are based upon the first test result from the triplicate test laboratories and the single test results from the other laboratories. Results of two properly conducted tests performed by two different laboratories with different operators using different equipment and on different days should not vary by more than the d2*s* limits shown in Table 4, Column 5. The results in Tables 3 and 4 are dissimilar because the data sets are different.

13.1.3 Table 3 presents a rigorous interpretation of triplicate test data in accordance with Practice E691 from pre-qualified laboratories. Table 4 is derived from test data that represents common practice.

13.1.4 *Soil Types*—Based on the multilaboratory test results the soils used in the program are described below in accordance with Practice D2487. In addition, the local names of the soils are given.

CH	Fat clay, CH, 99 % fines, LL=60, PI=39, grayish brown, soil had been air dried and pulverized. Local name—Vicksburg Buckshot Clay
CL	Lean clay, CL, 89 % fines, LL=33, PI=13, gray, soil had been air dried and pulverized. Local name—Annapolis Clay
ML	Silt, ML, 99 % fines, LL=27, PI=4, light brown, soil had been air dried and pulverized. Local name—Vicksburg Silt

13.2 *Bias*—There is no accepted reference values for this test method, therefore, bias cannot be determined.

14. Keywords

14.1 compaction characteristics; density; impact compaction; laboratory tests ; moisture-density curves; proctor test; soil; soil compaction; standard effort

ANNEX

(Mandatory Information)

A1. VOLUME OF COMPACTION MOLD

A1.1 Scope

A1.1.1 This annex describes the procedure for determining the volume of a compaction mold.

A1.1.2 The volume is determined by two methods, a water-filled and linear-measurement method.

A1.1.3 The water filling method for the 4-in. (106.5-mm) mold, when using a balance readable to nearest g, does not yield four significant figures for its volume, just three. Based on Practice D6026, this limits the density/unit weight determinations previously presented from four to three significant figures. To prevent this limitation, the water filling method has been adjusted from that presented in early versions of this test method.

A1.2 Apparatus

A1.2.1 In addition to the apparatus listed in Section 6 the following items are required:

A1.2.1.1 *Vernier or Dial Caliper,* having a measuring range of at least 0 to 6 in. (0 to 150 mm) and readable to at least 0.001 in. (0.02 mm).

A1.2.1.2 *Inside Micrometer (optional),* having a measuring range of at least 2 to 12 in. (50 to 300 mm) and readable to at least 0.001 in. (0.02 mm).

A1.2.1.3 *Depth Micrometer (optional)* , having a measuring range of at least 0 to 6 in. (0 to 150 mm) and readable to at least 0.001 in. (0.02 mm).

A1.2.1.4 *Plastic or Glass Plates*—Two plastic or glass plates about 8 in. square by ¼ in. thick (200 by 200 by 6 mm).

A1.2.1.5 *Thermometer or Other Thermometric Device,* having graduation increments of 0.1°C.

A1.2.1.6 *Stopcock Grease,* or similar sealant.

A1.2.1.7 *Miscellaneous Equipment*—Bulb syringe, towels, etc.

A1.3 Precautions

A1.3.1 Perform this method in an area isolated from drafts or extreme temperature fluctuations.

A1.4 Procedure

A1.4.1 *Water-Filling Method:*

A1.4.1.1 Lightly grease the bottom of the compaction mold and place it on one of the plastic or glass plates. Lightly grease the top of the mold. Be careful not to get grease on the inside of the mold. If it is necessary to use the base plate, as noted in 10.4.7, place the greased mold onto the base plate and secure with the locking studs.

A1.4.1.2 Determine the mass of the greased mold and both plastic or glass plates to the nearest 1 g and record, M_{mp}. When the base plate is being used in lieu of the bottom plastic or glass plate, determine the mass of the mold, base plate and a single plastic or glass plate to be used on top of the mold to the nearest 1 g and record.

A1.4.1.3 Place the mold and the bottom plastic or glass plate on a firm, level surface and fill the mold with water to slightly above its rim.

A1.4.1.4 Slide the second plate over the top surface of the mold so that the mold remains completely filled with water and air bubbles are not entrapped. Add or remove water as necessary with a bulb syringe.

A1.4.1.5 Completely dry any excess water from the outside of the mold and plates.

A1.4.1.6 Determine the mass of the mold, plates and water and record to the nearest 1 g, $M_{mp,w}$.

A1.4.1.7 Determine the temperature of the water in the mold to the nearest 0.1°C and record. Determine and record the density of water from the table given in Test Methods D854 or as follows:

$$\rho_{w,c} = 1.00034038 - (7.77 \times 10^{-6}) \times T - (4.95 \times 10^{-6}) \times T^2 \quad (A1.1)$$

where:

$\rho_{w,c}$ = density of water, nearest 0.00001 g/cm^3, and
T = calibration test temperature, nearest 0.1°C.

A1.4.1.8 Calculate the mass of water in the mold by subtracting the mass determined in A1.4.1.2 from the mass determined in A1.4.1.6.

A1.4.1.9 Calculate the volume of water by dividing the mass of water by the density of water. Record this volume to the nearest 0.1 cm^3 for the 4-in. (101.6-mm) mold or nearest 1 cm^3 for the 6-in. (152.4-mm) mold. To determine the volume of the mold in m^3, multiply the volume in cm^3 by 1 × 10^{-6}. Record this volume, as prescribed.

A1.4.1.10 If the filling method is being used to determine the mold's volume and checked by linear measurement method, repeat this volume determination (A1.4.1.3 – A1.4.1.9) and determine and record the average value, V_w as prescribed.

A1.4.2 *Linear Measurement Method:*

A1.4.2.1 Using either the vernier caliper or the inside micrometer (preferable), measure the inside diameter (ID) of the mold 6 times at the top of the mold and 6 times at the bottom of the mold, spacing each of the six top and bottom measurements equally around the ID of the mold. Record the values to the nearest 0.001-in. (0.02-mm). Determine and record the average ID to the nearest 0.001-in. (0.02-mm), d_{avg}. Verify that this ID is within specified tolerances, 4.000 ± 0.016 in. (101.6 ± 0.4 mm), if not discard the mold.

A1.4.2.2 Using the vernier caliper or depth micrometer (preferably), measure the inside height of the mold attached to the base plate. In these measurements, make three or more measurements equally spaced around the ID of the mold, and preferably one in the center of the mold, but not required (used the straightedge to facilitate the later measurement and correct measurement for thickness of straightedge). Record these values to the nearest 0.001-in. (0.02-mm). Determine and record the average of these height measurements to the nearest 0.001 in. (0.02 mm), h_{avg}. Verify that this height is within specified tolerances, 4.584 ± 0.018 in. (116.4 ± 0.5 mm), if not discard the mold.

A1.4.2.3 Calculate the volume of the mold to four significant digits in cm^3 as follows:

$$V_{lm} = K_3 \frac{\pi \times h_{avg} \times (d_{avg})^2}{4} \quad (A1.2)$$

where:

V_{lm} = volume of mold by linear measurements, to four significant digits, cm^3,
K_3 = constant to convert measurements made in inch (in.) or mm,
Use 16.387 for measurements in inches.
Use 10^{-3} for measurements in mm.
π = 3.14159,
h_{avg} = average height, in. (mm), and
d_{avg} = average of the top and bottom diameters, in. (mm).

A1.4.2.4 If the volume in m^3 is required, then multiply the above value by 10^{-6}.

A1.5 Comparison of Results and Standardized Volume of Mold

A1.5.1 The volume obtained by either method should be within the volume tolerance requirements of 6.1.1 and 6.1.2, using either or cm^3 to ft^3. To convert cm^3 to ft^3, divide cm^3 by 28 317, record to the nearest 0.0001 ft^3.

A1.5.2 The difference between the two methods should not exceed 0.5 % of the nominal volume of the mold, cm^3 to ft^3.

A1.5.3 Repeat the determination of volume, which is most suspect or both if these criteria are not met.

A1.5.4 Failure to obtain satisfactory agreement, between these methods, even after several trials is an indication the mold is badly deformed and should be replaced.

A1.5.5 Use the volume of the mold determined using the water-filling or linear method, or average of both methods as the standardized volume for calculating the moist density (see 11.4). This value (V) in cm^3 or m^3 shall have four significant digits. The use of a volume in ft^3, along with masses in lbm shall not be regarded as a nonconformance with this standard.

REFERENCES

(1) Johnson, A. W., and Sallberg, J. R., *Factors Influencing Compaction Test Results*, Highway Research Board, Bulletin 318, Publication 967, National Academy of Sciences-National Research Council, Washington, DC, 1962.

(2) *Earth Manual*, Unites States Bureau of Reclamation, Part 1, Third Edition, 1998, pp. 255–260.

(3) *Earth Manual*, Unites States Bureau of Reclamation, Part 2, Third Edition, 1990, USBR 5515.

(4) Torrey, V. H., and Donaghe, R. T., "Compaction Control of Earth-Rock Mixtures: A New Approach," *Geotechnical Testing Journal*, GTJODJ, Vol 17, No. 3, September 1994, pp. 371–386.

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this standard since the last issue (D698–07$^{\varepsilon 1}$) that may impact the use of this standard. (Approved May 1, 2012.)

(1) Revised 6.2.2.1 and 10.4.5.

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ATTACHMENT 6 – IMPLEMENTATION PLANS FOR SOIL AND SEDIMENT SAMPLING AND DU SURVEY

- **Soil and Sediment Sampling Implementation Plan (PDI SSS-1 and SSS-3)**
- **Depleted Uranium Penetrator Investigations Implementation Plan (PDI SSS-2)**
- **Cooling Pond, Sphagnum Bog, Septic Field, and Landfill Excavation Evaluations Implementation Plan (PDI SSS-4 and PDI HB-4)**

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REPORT ON

RD PRE-DESIGN INVESTIGATIONS – NMI SITE
SITE-WIDE SOILS AND SEDIMENTS
SOIL AND SEDIMENT SAMPLING IMPLEMENTATION PLAN
(PDI SSS-1 AND SSS-3)
CONCORD, MASSACHUSETTS

by
Haley & Aldrich, Inc.
Boston, Massachusetts

for
de maximis, inc.

File No. 131884-003
September 2020

Table of Contents

1. Objectives and Scope

The Pre-Design Investigation (PDI) activities for site-wide soils and sediments (SSS) will investigate the limits of chemical of concern (COC)-impacted soil and/or sediments (SSS-1), and the limits of site CoCs below the concrete slabs of the former buildings related to possible leaks from utilities (SSS-3). The results of PDI SSS-1 will be used to design the remedy to remove soil and/or sediments impacted by COC, while results of PDI SSS-3 will be used to design remedial investigations in conjunction with removal of the building slabs.

The objective of PDI SSS-1 is to define the horizontal and vertical extent of soil and/or sediment requiring remediation in several Areas of Interest (AOIs), including Areas A4 (AOI 9), A5 (AOI 8), and B2 (AOIs 2 and 4) due to the presence of PCBs, Area A6 (AOIs 7 and 11) due to the presence of depleted uranium, as well as PCBs.

The objective of PDI SSS-3 is to define the horizontal and vertical extent of contaminated soil below the former building slabs related to potential releases from floor drains, sumps, and subslab piping. The PDI includes collecting deeper subsurface soil at the four areas where significantly elevated uranium was identified during the NTCRA subslab investigation.

Details regarding the scope of work, including tables and figures for PDI SSS-1 and PDI SSS-3 were provided in the Remedial Design Work Plan - Appendix A Site-wide Soils and Sediment Pre-Design Investigation Work Plan, dated September 2020, in Attachments 1 and 3.

PDI INVESTIGATION	SITE AREA	PDI OBJECTIVES	PDI SCOPE
PDI-SSS-1	A4 (AOI 9) soil	PCBs and other COC delineation at northeast outfall area	Collect surface and shallow subsurface soil samples to refine delineation of COCs.
	A5 (AOI 8) soil	PCBs and other COC delineation at sweepings pile	Conduct borings to refine delineation of COCs.
	B2 (AOI 2 &4) soil	PCBs and other COC delineation within Cooling Pond Area	Collect surface and shallow subsurface samples to refine delineation of COCs.
PDI-SSS-3	Building footprints	Delineate uranium (based on subslab soil investigation performed as part of NTCRA)	Conduct borings through the existing floor slab to further evaluate the presence of COCs and to refine delineation of COCs for future excavation.

The procedures described below are augmented by the field sampling and laboratory procedures described in the Field Sampling Plan (FSP) and Quality Assurance Project Plan (QAPP). If applicable, work will be completed in accordance with the Health Physics Procedure (HPP) for Conduct of Radiological Work (HP-NMI-01). Additional references to standard operating procedures (SOPs) are added to specific work procedures listed below.

2. General Procedures

The following procedures will be considered for all proposed sampling for PDI SSS-1 and SSS-3, related to general access, sample processing and general post-sampling activities applicable to all proposed locations.

2.1 ACCESS

PDI SSS-1 will be conducted within several site areas and AOIs, and across varying field conditions, some of which will be challenging to access. Conditions at sampling locations include the following: wooded uplands, steeply sloped wooded areas, areas adjacent to wetland at the bottom of steep slopes or in wet wetland fringes, within wetlands with soft sediment present, and in standing water including ponds with deeper water present. Proposed explorations at the SSS-3 areas will be conducted from an existing concrete slab, directly accessible via existing paved roads at the site.

Prior to sampling, each proposed sampling location will be located using a hand-held GPS unit or by scaling off known existing features, and each location will be reviewed for access and general field condition considerations. For SSS-1 the majority of field locations where only shallow soil and sediment sampling is required are anticipated to be accessed on foot with hand-held equipment, typically in wooded areas. Pre-decontaminated (“clean”) or new sampling equipment, supplies, glassware, etc. will be mobilized to each AOI or sampling location, either carried by hand, transported using a wagon or sled, or using a field vehicle depending on accessibility. Routes to proposed sampling locations will be reviewed to follow general project guidelines related to different zones to be established at the site (eg. Contaminated Soil Zone, Contaminant Reduction Zone, etc.) Actual routes and paths through wooded areas will be determine to most safely access each sampling location, with least disturbance to the surrounding area. Although some limited clearing has been conducted at the site, additional clearing of small trees, branches, brush, leaves, etc. may be necessary to access the locations and to create individual sampling areas. Disturbance to surficial soils will be limited.

If there are sensitive areas where less surficial soil disturbance will be necessary due to the nature of contamination in the area (such as the Sweepings Area), access and other general procedures may be adjusted per location specific conditions and requirements.

Prior to drilling at locations up-slope from the bog straw wattles or coir rolls will be available on-site as necessary to mitigate for potential erosion or runoff from the drilling area into the bog or other wetland area.

If applicable, all equipment and tools that will enter the restricted area and that might contact radioactive contaminated areas are subject to screening by an HP according to the Radiological Surveys HPP (HP-NMI-05 in the Field Sampling Plan [FSP], RDWP Appendix I) to determine if background levels of radiation exist on the equipment prior to exposure to on-site soils. Additionally, disposable barriers may be applied as directed by the on-site HP or RSO to prevent contaminating equipment and tools while in the restricted area. The driller and consultant personnel are asked to only bring tools and equipment into the restricted area that are deemed essential to complete the task because tools and equipment will be subject to screening by HP and RSO before leaving the restricted area and, depending on impacts and ability to decontaminate, may have to be disposed of if contaminated.

Before entering the restricted area, workers will review and sign the specific radiation work permit for drilling and soil sampling activities and don the required personal protective equipment (PPE) and monitoring equipment as specified in the radiation work permit and/or instructed by the RSO or HP. Prior to initiating work, the staff will consult with the HP and RSO to determine an approach for screening and transporting equipment to the decontamination area and back so that work can progress efficiently.

For locations where a drill rig is utilized, the driller will create an exclusion zone around the drill rig. The exclusion zone does not need to be a physical barrier and may be demarcated with traffic cones. Only the driller and driller's helper should enter the exclusion zone. Other field personnel may enter the zone only when invited and supervised by the driller.

2.2 SAMPLE PROCESSING

At each land-based soil sample location, polyethylene sheeting will be placed to create a small, dedicated area to temporarily stage sampling equipment and supplies, and to process the soil samples. For sediment samples collected in wet areas (within or adjacent to wetlands, or in pond), sediment is anticipated to be collected at the sample locations, then transported to a safe location at a dry, stable area for sample processing.

Small sample processing areas will be constructed at each drilling/sampling location to process soil samples collected by the drilling rigs.

Refer to the applicable project-specific Field Sampling Plan (FSP) (Appendix I of the Remedial Design Work Plan, *de maximis,* September 2020), the Standard Operating Procedures (SOPs) located as Appendix I 1 of the FSP , and Quality Assurance Project Plan (QAPP) (Appendix G of the Remedial Design Work Plan, *de maximis,* September 2020) for further details related to sample processing, glassware, preservation, chains of custody, decontamination, and field documentation requirements and procedures for sample collection activities.

For activities where a drill rig is used, after work areas and processes have been established, drilling will commence with continuous sampling. Soil cores will be extracted and carried to the logging area by the driller or the driller's helper. The boring will be advanced, and the soil cores will continue to be extracted until the final depth of the boring is reached. The driller may proceed faster than the field engineer or geologist, so cores might need to be staged in liners near the logging area; however, the driller should not begin advancing the next boring until approved by the field engineer or geologist. After a soil core has been set in the logging area, the core liner will be cut open and logged by the field engineer or geologist using the USCS and following the soil description SOP (NMI-S-006, in the FSP).

If appropriate, soils will be initially screened with a handheld radiation survey instrument to ensure radiation levels are at a level where the core is safe to handle as determined by the HP and approved by the on-site RSO. If the soil is deemed unsafe by the HP or RSO, other protocols will be followed as directed by the HP or RSO. If the soil is safe to handle without further controls, the soils will be logged by the field engineer or geologist and following the soil description SOP (NMI-S-006, in the FSP). If the soil is deemed unsafe by the HP or RSO, other protocols will be followed as directed by the HP or RSO.

After logging, the soil core will be screened again using the handheld radiation survey instrument by the HP, and the count rate per minute will be logged.

2.3 FOLLOWING PROCESSING

After sample processing is completed, the dedicated sampling equipment will be bagged for disposal and the remaining equipment will be decontaminated prior to reuse. Refer to the Investigative Derived Waste (IDW) Handling and Storage (SOP NMI-005) and Field and Heavy Equipment Decontamination Procedures (SOP NMI-007) Standard Operating Procedures (SOPs)for additional details related to those items.

Following completion of the sampling, the completed as-sampled locations will be captured with a hand-held GPS unit. Completed sample locations will be also be marked with a flag or wood stake with flagging attached. Subsequently, all completed soil and sediment sampling locations will be surveyed by a professional land surveyor. Markers will be labeled with the sample location name. Note that marking locations may not be possible if located in deep water areas.

At the end of the sampling day, all soil and sediment samples collected will be screened by the onsite Radiological Laboratory to determine the concentration and total radioactivity prior to shipment. Gamma spectroscopy will be used to identify the isotope and assign activity present in each sample. The samples will be grouped to comply with Department of Transportation (DOT) and International Air Transport Association (IATA) guidelines. This data will also be provided to the receiving laboratory for approval prior to shipment.

If applicable, each time staff or equipment leaves the restricted area, they must be screened out of the restricted area under the guidance of the HP following the Personnel Monitoring and Decontamination HPP (HP-NMI-06, in the FSP) and sign out of the specific radiation work permit. All waste and PPE generated during the field event should be bagged appropriately and will be handled and dispose of as directed by the RSO and described in the investigation derived waste (IDW) handling and storage SOP (NMI-5 in the FSP) and Radioactive Waste HPPs HP-NMI-19 and HP-NMI-27 in the FSP. If soil IDW is generated that can be placed back in the borehole, it will be handled and stored following the IDW handling and storage SOP (NMI-5 in the FSP) and Radioactive Waste HPPs HP-NMI-19 and HP-NMI-27 in the FSP.

Prior to equipment and tools being released from the NMI site, additional decontamination may be needed and screening with swab samples will be required as described in the Heavy Equipment Decontamination and Free Release HPP (HP-NMI-25) and determined by the on-site RSO.

3. Implementation Procedures: PDI SSS-1 – Remedial Excavation Soil Characterization

See below for specific details related to surficial and subsurface soil sampling and for sediment sampling procedures for SSS-1.

3.1 SURFICIAL SOIL SAMPLING

For surficial soil (0 to 1-ft), sampling is proposed to be completed using a hand auger or other hand-held excavation device such as a shovel or hand trowel. Although not anticipated, a direct push (Geoprobe) and/or hollow-stem auger drill rig may be necessary for surficial soil sampling depending on field conditions.

Samples will be collected by advancing an approximate 3 to 4-in diameter stainless steel hand auger to 1-ft depth, or by manually hand excavating explorations using a shovel and/or hand trowel to a minimum dimension of approximately 6-in wide by 6-in long to 1-ft depth. Soil samples will be collected from the hand auger or from the side walls of the explorations, compositing the entire 1-foot depth interval in a stainless-steel bowl or disposable aluminum pan. The volume of collected material will be stirred to homogenize the sample and then placed in appropriate glassware for submission to the laboratory. If soil samples are collected using direct push and/or hollow-stem auger drill, see section below for sampling details.

The surficial soil samples are planned to be submitted for laboratory analysis of PCBs, polycyclic aromatic hydrocarbons (PAHs) (benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, and indeno(1,2,3-cd)pyrene), uranium, thorium, and arsenic.

3.2 SUBSURFACE SOIL SAMPLING

For deeper soil (greater than 1-foot depth), sampling is generally proposed to be completed by direct push (Geoprobe) and/or hollow-stem auger drill rig. Depending on field conditions, shallow subsurface samples (up to 2 feet) may be completed using a hand auger, shovel or hand trowel as was described above. Maximum depths of soil sampling for SSS-1 is anticipated to be 12-ft.

Sampling will likely be conducted using direct push methods via a Geoprobe® 6610DT rubber-track mounted direct push rig, or similar equivalent. Direct push explorations will be advanced in 5-ft intervals using 5-ft long Macro-Core® drill tooling with 1 7/8 in. I.D. Geoprobe® acetate liners, driven to the required depth below the ground surface (bgs). If a hollow-stem auger drill rig is used, explorations will be advanced in 2-ft intervals using 4-in diameter auger casing, with soil samples collected using 2-ft long split-spoon samplers. Upon retrieval of the liner core or split-spoon sampler, the sampler will be split or cut open for access to recovered soil.

Samples will then be collected by compositing soil from select depth intervals (generally on a 1 to 2 feet basis) in a stainless-steel bowl or aluminum pan. The volume of collected material will be stirred to homogenize the sample and then placed in appropriate glassware for submission to the laboratory.

Samples are planned to be submitted for laboratory analysis of PCBs, PAHs (benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, and indeno(1,2,3-cd)pyrene), uranium, thorium, and arsenic.

The general drilling soil logging and sampling activities will be conducted in accordance with SOP NMI-S-004 – Drilling and NMI-S-006 – Soil Description. Additional procedures related to radiological screening of the soil cores and coordination with the HP and RSO are outlined above.

Excess soil cuttings not used for analytical soil samples will be containerized and transported to the storage drum containment area. Upon completion, explorations completed deeper than 2 ft depth will be tremie-grouted with bentonite to ground surface, and the ground surface will be restored or graded to approximate existing surrounding conditions.

3.3 SEDIMENT SAMPLING

Sediment sampling is planned In the Former Drum Burial Area (AOI 2) and the Cooling Water Recharge Pond (AOI 4). Sediment sampling techniques will vary and be chosen depending on field conditions at time of sampling (depth of water, distance to shoreline, sediment types, etc.) and depending on depth intervals of sediment samples required, as follows:

1. Where shallow sediment sampling locations are dry and/or can be safely accessed on foot with minimal standing water present, and where only surficial sediment samples are required (up to 1-ft depth), sampling will be completed using a hand auger or other hand-held excavation device such as a shovel or hand trowel.

2. If sample locations can be access safely on foot which need to be sampled greater than 1-ft depth, a number of sediment sampling techniques may be used, including the following:
    a. If sediment is soft and loosely compacted consisting of a cohesive organic soil (silt), a Lexan® or polycarbonate approximate 2 or 3 in. ID tube sampling tube will used for sediment sample collection, as follows
        - The depth of water and location will be documented and recorded. The appropriate length of coring tube will be selected so that it could be driven into the sediment through the water column to the maximum depth of sampling.
        - For the initial attempt, the sample tube will pushed manually into the sediment to the bottom of the deepest sample interval depth. A cap would then be placed on the top of the tube and the tube then extracted with a sediment core collected within the tube. If the sediment material appears to be loose and may release from the bottom of the coring tube, a cap will be affixed to the bottom of the core prior to lifting it out of the water.

    If the collected sediment is falls out the bottom of the coring tube and sample cannot be recovered, the sampling tube will be fitted with a sliding rubber piston to maintain suction in the tube while advancing the sampler, which better prevent softs sediment from escaping the coring tube during extraction.

        - Prior to advancing the core, a piston is placed into the sample tube and the seals will be checked to ensure a tight fit. The piston will be placed approximately 1-ft above the bottom of the sample tube.

- The sample core tube will be lowered through the water column to the measured depth of the bottom. The line attached to the piston will be secured to allow the polycarbonate tube to slide past the piston as the tube is pushed into the sediment – the piston remains in place and does not move while the core tube advances into the sediment.
- The tube is then pushed manually into the sediment until the bottom of the deepest sample interval depth or refusal.
- The coring tube will then be pulled out of the sediment and lifted through the water column. As the bottom of the polycarbonate tube approached the water surface, a cap will be affixed to the bottom of the core prior to lifting the sample out of the water. After placing the bottom cap, the core will be positioned upright. Standing water preset above the piston will drained, the tube will be trimmed, the piston removed, and if necessary, another cap will be placed on the top of the tube.
- Location ID, orientation, and total penetration depth will be recorded on the top cap. Cores will be transferred to the onshore work area in an upright position
- Once the cores are transferred to the processing area, they will be left undisturbed momentarily to allow settling of suspended solids.
- After the standing water above the sediment was visibly clear, holes will be drilled into the core tube to drain excess water above the sediment core. After the water is drained, the cores will be placed horizontally to allow for logging and processing.
- Prior to processing the cores, additional aluminum foil or polyethylene sheeting will be placed on top of the work surface to prevent cross-contamination. If needed to access sediment from within the core tube, electric sheers will be used to cut open the core tube. Total recovery will be measured and the core will be the logged and photographed.
- Prior to collecting the sediment samples from the core tube, the cores will be segregated into sample intervals representative of depth intervals required for sampling. The sample intervals will be based on recovery and the entire core will assumed to compact uniformly. (For example, if the core recovery was 75% of the total penetration, the top 6 inches of the sediment layer will be assumed to be the top 4.5 inches of sediment recovered in the core.) After calculating sample intervals based on recovery, cores will be sectioned and the sediment sampled.

b. If sediment is densely compacted or consists of a coarser sand and gravel (rather than cohesive organic material), and if the sediment can be removed to the maximum depth required without the cored hole collapsing prior to reaching that depth, a hand auger will be used.

c. If sediment is densely compacted or consists of a coarser sand and gravel and the sediment <u>cannot</u> be removed to the maximum depth required without the cored hole collapsing, the following will be attempted:

- The 0-1 ft surface sediment sample will be collected either by hand using a hand auger or trowel. If the conditions do not allow collection by hand auger or trowel, an open-ended plastic cylinder will be driven into the ground surface to an approximate depth of 1 ft, which would isolate the sample area from surrounding loose wetland soils and preventing surface water from entering the excavation area. The sample was collected from inside the cylinder using a hand trowel.

- After the initial surficial sample interval is collected, a 4 in. diameter section of Schedule 40 PVC pipe will be hand driven to the maximum sampling depth. Installation of the PVC pipe drive pipe will prevent the borehole from collapsing and prevented surface water and loose sediments present around the area of excavation from mixing with the samples collected from the depth intervals. Sediment will be sampled by removing the material from within the drive pipe using a hand auger.

3. If sample locations are present within several feet of standing water and cannot be accessed safely on foot, a boat may be needed to facilitate sampling. Again, actual sampling equipment and techniques will be dependent on standing water depth, sediment type and sample depths. Sampling equipment and techniques described above may be used from a boat to collect sediment samples.

4. If sample locations cannot be collected using hand methods described above (hand auger, trowel, core tube, etc.) either by foot or from a boat, a direct push (Geoprobe) boring rig or a vibracore rig will be used to access and sample the sediment.

Sediment samples will be composited over either 1 or 2-ft depth intervals in a stainless-steel bowl or disposable aluminum pan. The volume of collected material will be stirred to homogenize the sample and then placed in appropriate glassware for submission to the laboratory.

Samples are planned to be submitted for laboratory analysis of PCBs, PAHs (benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, and indeno(1,2,3-cd)pyrene), uranium, thorium, arsenic, copper, lead, and mercury. If the laboratory determines that the sample has less than 30% solids, a new sample will be collected with a greater sample volume, as necessary. In the field, if it appears the sample is overly wet, additional sample volume will be collected and submitted to the laboratory.

4. Implementation Procedures: PDI SSS-3 – SUBSLAB Soil Characterization

4.1 CONCRETE CORING OF THE FORMER BUILDING SLABS

In order to facilitate collection of samples below the former building slabs without compromising the slab or disturbing the soil beneath, a concrete coring subcontractor will be employed to core through the existing slab. This will allow a drill rig to access the soil beneath the slab without damaging the drilling equipment or without the need to remove sections of concrete slab and disturb the soil beneath. It will also provide further detail about the thickness of the concrete slab at the specified locations.

The contractor will core through the concrete slab to create an approximately 4-inch diameter hole. The concrete core will be placed aside for appropriate disposal during future activities. If obstructions are encountered during the subsurface sampling phase, sampling locations may need to be moved which would require additional locations to be cored through the slab.

4.2 SUBSURFACE SAMPLING

Following slab coring, soil sampling is generally proposed to be completed at each location using a direct push (Geoprobe) and/or hollow-stem auger drill rig. Sampling will likely be conducted using direct push methods via a Geoprobe® 6610DT rubber-track mounted direct push rig, or similar equivalent. To minimize impact to the flexible membrane liner covering the slab, plywood or maybe mats will be used to protect the liner for transport of the drill rig onto the slab and from exploration to exploration location.

Explorations will be advanced in 5 ft intervals using 5 ft long Macro-Core® drill tooling with 1 7/8 in. I.D. Geoprobe® acetate liners, driven to the appropriate depth below the ground surface (bgs). Upon retrieval of the liner core, 2-ft composite soil samples will be collected from the following depth intervals: 4 to 6 feet, 6 to 8 feet, 8 to 10 feet, 10 to 12 feet, 12 to 14 feet, 14 to 16 feet, 16 to 18 feet, 18 to 20 feet, 20 to 22 feet, 22 to 24 feet, and 24 to 26 feet.

The general drilling soil logging and sampling activities will be conducted in accordance with SOP NMI-S-004 – Drilling and NMI-S-006 – Soil Description. Additional procedures related to radiological screening of the soil cores and coordination with the HP and RSO are outlined above.

Samples will be collected by compositing soil from select depth intervals in a stainless-steel bowl or aluminum pan. The volume of collected material will be stirred to homogenize the sample and then placed in appropriate glassware for submission to the laboratory.

Samples are planned to be submitted for laboratory analysis of uranium, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs) (benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, and indeno(1,2,3-cd)pyrene), arsenic, and thorium.

Excess soil cuttings not used for analytical soil samples will be containerized and transported to the storage drum containment area. Upon completion, explorations will be tremie-grouted with a Portland cement and bentonite grout mix to ground surface. The flexible membrane liner will be patched following demobilization of the drilling equipment.

REPORT ON

RD PRE-DESIGN INVESTIGATIONS – NMI SITE
SITE-WIDE SOILS AND SEDIMENTS
DEPLETED URANIUM PENETRATOR INVESTIGATIONS
IMPLEMENTATION PLAN (PDI SSS-2)
CONCORD, MASSACHUSETTS

by
Haley & Aldrich, Inc.
Boston, Massachusetts

for
de maximis, inc.

File No.131884-003
September 2020

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1. Objectives and Scope

This Pre-Design Investigation (PDI) activity for site-wide soils and sediments (SSS) will evaluate the presence of depleted uranium (DU) in soil from DU penetrators and metal fragments. The scope of this investigation will be based on results of the prior Non-Time-Critical Removal Actions (NTCRAs), including verifying removals performed in the NTCRAs and further evaluating areas of concern identified in the NTCRAs. The results of PDI SSS-2 will be used to confirm prior removals of soil impacted by DU metal fragments and assess the presence of DU metal fragments in deeper soil (greater than 6 inches deep).

The objectives for this PDI are to evaluate the presence of DU penetrators and metal fragments at the site, remove any identified DU penetrators/metal fragments and associated impacted soil, and conduct delineation sampling at areas where DU penetrators/metal fragments were previously removed and from areas identified in this walkover survey.

The scope of work as follows:

- Perform DU gamma walkover survey of surficial soil to evaluate the presence of DU metal fragments.
- Excavate/scrape soil back to a depth of 6-inches and windrow the soil adjacent to the area exposed. Perform DU gamma walkover survey of deeper soil to evaluate the presence of DU metal fragments.
- Remove soil and DU fragments at any locations identified in shallow and deeper soil areas surveyed.
- Collect soil samples at previously remediated locations and newly excavated locations to confirm complete removal of DU penetrators/metal fragments and impacted soil to meet the Remedial Action Objectives (RAOs). Data collected will be used to delineate the limits of excavation necessary as part of the 30% Remedial Design (RD).

2. General Procedures

The following procedures will be considered for all proposed sampling for PDI SSS-2, related to general access, processing and post-sampling activities.

2.1 ACCESS

PDI SSS-2 will be conducted within several areas of site. Conditions at survey and sampling locations include the following: near the edge of parking areas, building exteriors, and the fence line, as well as along the edge of paved surfaces. One area of the DU penetrator survey extends from the edge of the paved surface down the slope toward the northern wetlands. The majority of the DU penetrator survey is along the fenceline and to the break in slope before it rises or drops off in elevation.

Prior to sampling, each proposed sampling location will be located using a hand-held GPS unit or by scaling off known existing features, and each location will be reviewed for access and general field condition considerations. Pre-decontaminated ("clean") or new sampling equipment, supplies, glassware, etc. will be mobilized to each survey or sampling location, either carried by hand or transported using a wagon sled or using a field vehicle depending on accessibility. Routes to proposed sampling locations will be reviewed to follow general project guidelines related to different zones to be established at the site (e.g., Contaminated Soil Zone, Contaminant Reduction Zone, etc.). Actual routes and paths will be determined to most safely access each sampling location, with least disturbance to the surrounding area. Although some limited clearing has been conducted at the site, additional clearing of branches, brush, leaves, etc. may be necessary to access the locations and to create individual sampling areas may be necessary. Disturbance to surficial soils will be limited.

If there are sensitive areas where less surficial soil disturbance will be necessary due to the nature of contamination in the area (e.g. sphagnum bog), access and other general procedures may be adjusted per location specific conditions and requirements.

2.2 SAMPLE PROCESSING

At each land-based soil sample location, polyethylene sheeting will be placed to create a small, dedicated area to temporarily stage sampling equipment and supplies, and to process the soil samples.

Refer to the applicable project-specific Standard Operating Procedures (SOPs) located as Appendix I 1 of the Field Sampling Plan (FSP) (Appendix I of the Remedial Design Work Plan, *de maximis,* September 2020), the (FSP) (Appendix I of the Remedial Design Work Plan, *de maximis,* September 2020) and Quality Assurance Project Plan (QAPP) (Appendix G of the Remedial Design Work Plan, *de maximis,* March 2020) for further details related to sample processing, glassware, preservation, chains of custody, decontamination, and field documentation requirements and procedures for the sample collection activities.

2.3 FOLLOWING PROCESSING

After sample processing is completed, the dedicated sampling equipment will be bagged for disposal and the remaining equipment will be decontaminated prior to reuse. Refer to the Investigative Derived Waste (IDW) Handling and Storage (SOP NMI-005) and Field and Heavy Equipment Decontamination

Procedures (SOP NMI-007) Standard Operating Procedures (SOPs)for additional details related to those items.

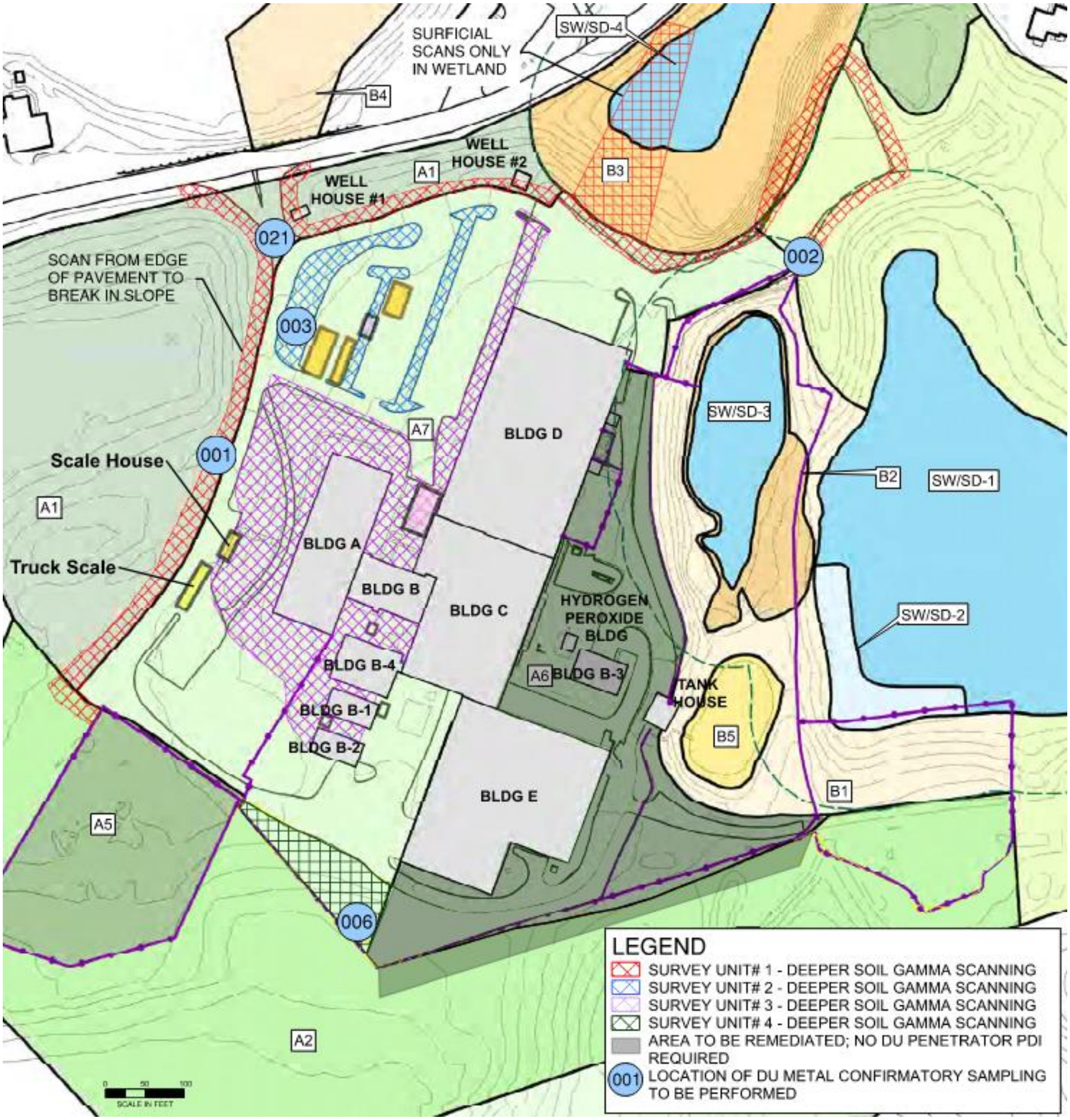
Following completion of the sampling, the completed soil sampling locations will be captured with a hand-held GPS unit. Completed soil sample locations will be marked with a flag or wood stake with flagging attached. Markers will be labeled with the sample location name.

At the end of the sampling day, soil samples collected will be provided to the site Radiation Safety Officer for screening prior to final packing and submittal to the analytical laboratory.

3. Implementation Procedures: DU Survey and Soil Characterization

3.1 DU GAMMA WALKOVER SURVEY

The DU Gamma Walkover survey is planned to be completed over approximately 17,100 square yards of the site where remedial excavations are not already planned. This area will be divided into 4 survey units (SU 1, 2, 3, and 4). Prior to completing the surveys, survey grids will be created for the survey units mentioned above and the areas will be grubbed/cleared to minimize interferences. Gamma walkover surveys will be performed one survey unit at a time. The Figure below shows the limits of DU Survey.


SURFICIAL SCANS ONLY IN WETLAND
SW/SD-4
B4
B3
WELL HOUSE #2
A1
WELL HOUSE #1
021
002
SCAN FROM EDGE OF PAVEMENT TO BREAK IN SLOPE
003
SW/SD-3
A7
BLDG D
001
Scale House
A1
B2
SW/SD-1
BLDG A
Truck Scale
BLDG B
BLDG C
HYDROGEN PEROXIDE BLDG
SW/SD-2
BLDG B-4
A6
BLDG B-3
TANK HOUSE
BLDG B-1
B5
BLDG B-2
BLDG E
B1
A5
006
A2
0 50 100
SCALE IN FEET
LEGEND
SURVEY UNIT# 1 - DEEPER SOIL GAMMA SCANNING
SURVEY UNIT# 2 - DEEPER SOIL GAMMA SCANNING
SURVEY UNIT# 3 - DEEPER SOIL GAMMA SCANNING
SURVEY UNIT# 4 - DEEPER SOIL GAMMA SCANNING
AREA TO BE REMEDIATED; NO DU PENETRATOR PDI REQUIRED
001 LOCATION OF DU METAL CONFIRMATORY SAMPLING TO BE PERFORMED

If any elevated areas are identified during the gamma walkover survey, they will be marked (pin flag, stake, paint) and additional investigations will be performed only at those specific locations. Any areas with pin flags will have a 5 ft. zone cordoned off to be investigated with all other pin-flagged areas requiring hand digging or excavation to remove DU or impacted soil.

Once the first surficial scan is completed, the survey will continue by removing approximately 6 inches of soil from the areas previously scanned and identified as being within background limits. The 6-inches of soil will be excavated/scraped with a mini-excavator and will be temporarily windrowed adjacent to the area of removal. This will allow for the soil to be backfilled at the same location as it was removed. The excavator or other equipment will not be allowed within the areas exposed for the survey.

If any elevated areas are identified in the deeper zone, pin flags will be set and a 5-foot zone around the pin flag will be established. Soil windrowed within areas identified as being less than 3x instrument background will be backfilled. Each surficial and deeper pin-flagged areas will remain flagged for excavation and sampling, and will be cordoned off with caution tape to limit access.

The Gamma walkover surveys will be completed with a shielded 2x2 sodium iodide (NaI) detector coupled with a submeter accuracy GPS. Gamma walkover surveys will be performed by holding the NaI detector as close to the ground surface as possible (less than 4 inches from surface), moving it side-to-side while walking slowly (approximately 1 foot per second). Continue gamma walkover surveys in one direction until survey unit boundary has been reached, then turnaround and return, offset from the completed path to continue the walkover survey so that full coverage of the area is achieved. Repeat this survey process until the survey unit has been completed. Any elevated results will be initially evaluated by pausing over the location to determine if the elevated results are consistent. If not, then continue with gamma walkover surveys. If consistently elevated above the action level (3x instrument background), that location will be marked (pin flag, stake, paint) for additional investigations.

Gamma walkover surveys performed in this manner have a sensitivity of 56 pCi/g or total radioactivity of 3.3 uCi or approximately 10 g of DU metal at depth up to 6 inches in soil. Background will be established for each survey unit prior to gamma walkover survey and this background will be the basis for the action level in the survey unit. If there are significant changes to the soil type in a survey unit such that background changes, then a new background can be established for a portion of a survey unit.

3.2 INVESTIGATION OF ELEVATED NAI MEASUREMENTS

At each pin-flagged location with If elevated NaI measurements, the location will be recorded by GPS and the source of the elevated area will be investigated by hand digging in the area. Removed material will be screened with the NaI to determine if the source has been removed and/or identify it. The soil removed from the elevated area will be placed in a drum or roll-off. If the area continues to be elevated by NaI, but no metal fragments are apparent, the procedure described above will be performed, and an additional six inches of soil will be scraped back and the newly exposed ground surface scanned until no elevated NaI measurements are recorded.

If DU fragments are the source of the elevated NaI readings, the soil around the fragments will be removed (minimum of three feet diameter) and then scanning the newly exposed ground surface. The excavated soil removed from the areas with elevated gamma readings will be placed in drums or roll-offs depending on the volume removed. Each of these areas will have hand excavation and/or soil sieving will be conducted to retrieve and dispose of any DU penetrator/metal fragments. The soil surrounding the metal fragment(s) and any visibly impacted soil will be removed. The DU metal fragments will be drummed in 55-gallon drums. Soil removed will be either drummed or placed in a roll-off container, depending on the volume generated. It is expected that smaller volumes will be generated with this round of survey, so drums are expected to be adequate.

There is no planned stockpiling of soil as the goal is to only remove DU fragments and any soil touching the DU fragments from the site. In the event it makes sense to chase out an area now with DU fragments and impacted soil that may exceed a roll-off, then an area of the site will be set up to manage a soil stockpile.

The stockpile area will be set up on a paved area, with three-sides of jersey barriers and coir rolls will be laid across the opening of the stockpile area prior to leaving on a daily basis. If the stockpile remains for more than 1-week, it will be covered with polyethylene. If a soil stockpile is necessary. The stockpiled soil will be characterized by testing the site wide COCs for the material to be reused to backfill the surveyed area.

Soil sampling of the excavations will be performed as described in the Delineation Soil Sampling section below.

3.3 DELINEATION SOIL SAMPLING

A background soil sample will be collected from each Survey Unit area to correlate the gamma scanning instrument to analytical data to the extent possible. Background soil samples will be submitted for laboratory analysis of all site COCs, including uranium, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs) (benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, and indeno(1,2,3-cd)pyrene), arsenic, and thorium.

Following collection of background samples, at each of the five (5) former DU penetrator/metal fragment soil removals performed during the NTCRA (001, 002, 003, 006, and 021), an initial gamma scan of the area will be conducted using a shielded 2x2 sodium iodide (NAI) detector. Following the scan and confirming background conditions, four discrete horizontal soil samples will be collected approximately 90 degrees from each other, each approximately 1 foot away from edge of the former soil removal area. A discrete vertical sample will also be collected at the bottom of the former removal area.

At each pin-flagged location that had material removed to achieve background with the NaI detector, soil samples will be collected. Horizontal surficial samples will be collected by advancing an approximate 3 to 4-in diameter stainless steel hand auger to 1-ft depth, or by manually hand excavating explorations using a shovel and/or hand trowel to a minimum dimension of approximately 6-in wide by 6-in long to 1-ft depth . Vertical soil samples will be collected to depths of 1-ft from the bottom of the removal area, composited from a minimum dimension of approximately 6-in wide by 6-in long.

Soil samples will be collected from the hand auger or from the side walls of the explorations, compositing the entire depth interval in a stainless-steel bowl or disposable aluminum pan. The volume of collected material will be stirred to homogenize the sample and then placed in appropriate glassware for submission to the laboratory.

Samples will be submitted for laboratory analysis of all site COCs, including uranium, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs) (benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, and indeno(1,2,3-cd)pyrene), arsenic, and thorium.

Each area sampled will be restored by placing a non-woven geotextile on the small excavation and then backfilling with soil from the windrow or off-site fill. The area will be backfilled flush with grade and flagged.

If necessary, following review of the results from the sampling program described above, additional sampling may need to be performed to excavate the remaining DU penetrator/metal fragment impacted soil. The areas will be excavated to expose the geotextile and an additional 1 to 2 feet of soil horizontally from the impacted sidewall or an additional 6 inches vertically from the impacted bottom will be excavated, and then the newly exposed sidewall or bottom will be resampled for site COCs. Excavated soil will be placed in drums or roll-offs for future off-site management. The data collected will be used as part of the overall site wide soil delineation of the limits requiring excavation to meet the proposed cleanup levels (PCLs) summarized in the Record of Decision.

3.4 BACKFILLING AND SITE RESTORATION

Soil that was excavated and windrowed next to the survey area will be reused as backfill. This soil will be placed as closely to the original location as possible. Soil that is removed from elevated NaI readings will be placed in drums or a roll-off for off-site management. The small excavations needed to remove the DU fragments and the impacted soil will be backfilled with off-site material such as crushed stone or granular backfill placed on the geotextile. The surface treatments will also be restored to original surfaces.

If it is deemed necessary to stockpile soil this material will be tested for site COCs, and if the concentrations are below PCLs, the soil will be used as backfill to establish original grades. If soils exceed PCLs, the soil will be placed in roll-offs and managed off-site accordingly.

If it appears that more than 2-roll offs are necessary to manage the soil around the identified DU, this work may become part of the 30% RD. This work is intended to be Pre-Design work and the conclusion may be to extend the lateral and vertical extent of soil excavations along these areas of the proposed DU survey. As described above, the analytical data collected as part of this PDI will be used to delineate the limits of excavation shown in the 30% RD.

REPORT ON

RD PRE-DESIGN INVESTIGATIONS – NMI SITE
SITE-WIDE SOILS AND SEDIMENTS
COOLING POND, SPHAGNUM BOG, SEPTIC FIELD AND LANDFILL EXCAVATION EVALUATIONS IMPLEMENTATION PLAN
(PDI SSS-4 AND PDI HB-4)
CONCORD, MASSACHUSETTS

by
Haley & Aldrich, Inc.
Boston, Massachusetts

for
de maximis, inc.

File No. 131884-003
September 2020

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1. Objectives and Scope

The Pre-Design Investigation (PDI) activity for site-wide soils and sediments (SSS) will investigate the characteristics of the Cooling Pond, the Sphagnum Bog, the Landfill, and the Gabion Wall. The results of PDI SSS-4 will be used to design the remedial excavations at each area. Sediment within the Cooling Pond and Bog are also being evaluated for geotechnical properties in order to conduct the appropriate slope stability analyses as outline in PDI HB-4.

The objectives for performing the testing described in this PDI are as follows:

- Assess the potential for and delineate the limits of buried debris within the remedial excavation areas at the Landfill and within the former septic fields.
- Evaluate the slope stability of several areas proposed for remedial excavation areas and of the Gabion Wall.
- Evaluate the groundwater-surface water interaction and groundwater-sediment relationship at the Cooling Pond.
- Characterize and inventory existing wetland conditions at the Sphagnum Bog and Cooling Pond.
- Complete six transects with up to three probes each within the Cooling Pond, and Five transects within the bog, and three transects down slope of Holding Basin and bog.

The results of these investigations will provide the data for PDI SSS-4 and PDI HB-4. The data and subsequent analysis will support the design of remedial excavations and inform the wetland restoration requirements following the remedial excavations.

The scope of work for this PDI includes a geophysical survey, collection of field data to support the slope stability analysis, and collection of field data on shallow geology along site slopes, sediment and groundwater chemistry at the Cooling Pond, and information on the inventory and limits of existing wetland conditions at the Cooling Pond and Sphagnum Bog.

2. General Procedures

The following procedures will be considered for all proposed sampling for PDI SSS-4, related to general access, processing and post-sampling activities.

2.1 ACCESS

PDI SSS-4 will be conducted within several site areas and AOIs, and across varying field conditions, some of which will be challenging to access. Conditions at sampling locations include the following: within sphagnum bog wetland areas, within wetlands with soft sediment present, or in standing water including ponds with deeper water present.

Prior to sampling, each proposed sampling location will be located using a hand-held GPS unit or by scaling off known existing features, and each location will be reviewed for access and general field condition considerations. Pre-decontaminated ("clean") or new sampling equipment, supplies, glassware, etc. will be mobilized to each AOI or sampling location, either carried by hand or transported using a wagon sled or using a field vehicle depending on accessibility. Routes to proposed sampling locations will be reviewed to follow general project guidelines related to different zones to be established at the site (eg. Contaminated Soil Zone, Contaminant Reduction Zone, etc.). Actual routes and paths through wooded areas will be determined to most safely access each sampling location, with the least disturbance to the surrounding area. Although some limited clearing has been conducted at the site, additional clearing of branches, brush, leaves, etc. may be necessary to access the locations and to create individual sampling areas may be necessary. Disturbance to surficial soils will be limited.

If there are sensitive areas where less surficial soil disturbance will be necessary due to the nature of contamination in the area (e.g. sphagnum bog), access and other general procedures may be adjusted per location specific conditions and requirements.

2.2 SAMPLE PROCESSING

At each land-based soil sample location, polyethylene sheeting will be placed to create a small, dedicated area to temporarily stage sampling equipment and supplies, and to process the soil samples. For sediment samples collected in wet areas (within or adjacent to wetlands, or in pond), sediment samples are anticipated to be collected at the sample locations, then transported to a safe location at a dry area for processing. For groundwater or surface water sampling from piezometers installed where water or soft sediment is present at the surface, equipment may be transported and staged on a floating sled or bin. If piezometers are located where enough standing water is present which prevent safe access by foot, a boat may be used to access piezometer locations and to collect/process samples.

Details related to soil borings (if required) are discussed in the Drilling Implementation Plan, separate from this Implementation Plan. Small sample processing areas will be constructed at each drilling/sampling location to process soil samples collected by the drilling rigs.

Refer to the applicable project-Field Sampling Plan (FSP) (Appendix I of the Remedial Design Work Plan, *de maximis,* September 2020), the Standard Operating Procedures (SOPs) located as Appendix I 1 of the FSP , and Quality Assurance Project Plan (QAPP) (Appendix G of the Remedial Design Work Plan, *de maximis,* September 2020) for further details related to sample processing, glassware, preservation, chains of custody, decontamination, and field documentation requirements and procedures for the sample collection activities.

2.3 FOLLOWING PROCESSING

After sample processing is completed, the dedicated sampling equipment will be bagged for disposal and the remaining equipment will be decontaminated prior to reuse. Refer to the Investigative Derived Waste (IDW) Handling and Storage (SOP NMI-005) and Field and Heavy Equipment Decontamination Procedures (SOP NMI-007) Standard Operating Procedures (SOPs)for additional details related to those items.

Following completion of the sampling, the completed piezometer, soil and sediment sampling, or sphagnum bog peat probing locations will be captured with a hand-held GPS unit. Completed sediment and soil sample locations will be marked with a flag or wood stake with flagging attached. Subsequently, all completed piezometer, probing and sampling locations will be surveyed by a professional land surveyor. The elevation of the reference mark on the piezometers will also be determined by the surveyor. Markers will be labeled with the sample location name.

At the end of the sampling day, all soil and sediment samples collected will be screened by the onsite Radiological Laboratory to determine the concentration and total radioactivity prior to shipment. Gamma spectroscopy will be used to identify the isotope and assign activity present in each sample. The samples will be grouped to comply with Department of Transportation (DOT) and International Air Transport Association (IATA) guidelines. This data will also be provided to the receiving laboratory for approval prior to shipment.

3. Implementation Procedures: Cooling Water Recharge Pond (AOI4) Piezometer Install, Groundwater and Sediment Characterization

3.1 PIEZOMETER INSTALLATION

Up to 12 piezometers will be installed by hand in couplets of two within the Cooling Pond to evaluate shallow and deeper hydrogeologic conditions within the sediment and shallow underlying sand material present at the Pond. At each of the six proposed couplet location, one shallow piezometer will be installed with the screened section within the soft, organic sediment layer, and a second piezometer with the screen in the deeper sand layer underlying the soft sediment.

Although the RDWP indicates piezometer screens depths of 3 ft for the shallow and 6-ft for the deeper locations and that piezometers will have a 6-in long screen present, these were only estimates; actual screen lengths, intervals and depths will be determined in the field after actual thickness of sediment and depth to the sand layer are established at each of the proposed couplet location. Piezometers will be constructed and installed as follows:

- The piezometers will consist of the Solinst® Model 615 screened drive-point piezometer heads driven to proposed groundwater sampling depths which will be attached to a steel riser pipe extending to the surface. The ¾ in. diameter stainless steel drive point heads will have either a 6-in or a 1 ft long 50 mesh screened section and will be connected to ¾ in. diameter galvanized riser pipe. Prior to installation, a section of 5/8 in. OD HDPE tubing will be attached to the piezometer head which will run through the riser pipe to the surface. At the end of the steel riser pipe, a ¾ in. threaded to slip PVC coupling will be attached, and an approximate 12 in. long, ¾ in. diameter PVC section with removable cap will installed onto the coupling at the end of the piezometer system. The HDPE tubing will extend into the PVC pipe section and will be access by removing the pipe from the riser at the coupling. The PVC pipe at the end of the system will scored for venting and a reference point will be marked on the PVC coupling for elevation and groundwater level measurements.
- Piezometer systems will be driven to the appropriate depth using a handheld, manual slide hammer and a Solinst manual drive head assembly which allows the piezometer to be installed while the HDPE tubing is in place.
- Following installation of the piezometer, approximately 6 inches of bentonite chips will be placed around the base of the piezometers to isolate potential cross communication of groundwater and surface water.
- During and following installation of the piezometer system, the following information will be collected and recorded:
  - Depth of water,
  - Depth of soft sediment,
  - Depth of surface water from reference point on piezometer,
  - Depth to pond bottom from reference on piezometer, and
  - Depth installed below sand layer.
- A length of ½ in. OD HDPE tubing will be affixed on the side of the steel riser pipe on the piezometer, with the intake end placed approximately one half the depth of the surface water

to facilitate future surface water sampling. The other (surface) end of the tubing will either be run to the shoreline, coiled and strapped to a nearby structure, or will be coiled at the piezometer location above the surface water level.

Up to 4 rounds of head measurements will be collected from the 12 piezometers. Information on head differentials between the shallow and deep sediment wells will inform our understanding of the interaction between groundwater and surface water.

3.2 GROUNDWATER AND SURFACE WATER SAMPLING

Up to 12 groundwater samples will be collected from the Cooling Pond - one sample collected from each newly installed piezometer. Groundwater quality data will be used in conjunction with head measurements and sediment quality data to evaluate the potential for contaminants to transport between sediment and groundwater. One discrete surface water sample will be collected from the center of the Pond during the groundwater sampling round.

Sampling will be performed using low-flow methodology as outlined in the EPA Low-Stress (Low-Flow) Standard Operating Procedure EQASOP-GW4, as summarized in NMI-GW-010 SOP. At the piezometer locations, groundwater sampling equipment will be connected to the existing HDPE tubing permanently affixed to the piezometer head. In general, during low-flow purging a multi-parameter meter will be used to measure pH, specific conductivity, turbidity, dissolved oxygen, oxidation reduction potential (ORP) and temperature. Readings will be collected at 5-minute intervals and recorded on field logs. Once parameters are stable with turbidity reduced to an acceptable level, groundwater samples will be collected into laboratory provided glassware. Due to the nature of piezometers installed within cohesive material such as sediment, and that short screened sections will be installed within the piezometers (6-in or 1-ft), strict conformance of the low-flow sampling operating procedures discussed above may not be possible. If so, sampling procedures will be evaluated on a case-by-case basis.

Field instruments will be inspected and calibrated at the beginning of each day and checked during field activities to verify performance. Instrument specific calibration procedures will be performed in accordance with the instrument manufacturer's requirements.

Groundwater samples will be submitted to a National Environmental Laboratory Accreditation Program (NELAP) accredited laboratory for analysis of chlorinated volatile organic compounds (CVOCs), uranium, copper and total organic carbon (TOC). Uranium is the primary contaminant of concern in groundwater at the Cooling Pond. The addition of copper, chlorinated VOCs, and TOC data will be used to calculate the sorption from groundwater to sediment.

The surface water sample location will be as close to the center of the pond, within the center of the water column to collect a representative sample of surface water during the groundwater sampling event. Similar sampling procedures as the groundwater sampling described above will be implemented. The surface water sample will also be tested for the same parameters as the groundwater.

3.3 SEDIMENT SAMPLING

Up to 12 sediment samples will be collected at the locations of the proposed piezometers within the footprint of the Cooling Water Recharge Pond (AOI 4). Sediment samples will be collected from the approximate depth intervals where the well screens are installed at each piezometer within the couplet;

one sample from within the soft, organic sediment layer, and a second from the deeper sand layer underlying the soft sediment. Sediment sampling techniques will vary and be chosen depending on field conditions at time of sampling (depth of water, distance to shoreline, sediment types, etc.) and depending on depth intervals of sediment samples required, as follows:

- If sample locations greater than 1 ft in depth can be accessed safely on foot, a number of sediment sampling techniques may be used, including the following:

    a. If sediment is soft and loosely compacted consisting of a cohesive organic soil (silt), a Lexan® or polycarbonate approximate 2 or 3 in. ID tube sampling tube will used for sediment sample collection, as follows:

        - The depth of water and location will be documented and recorded. The appropriate length of coring tube will be selected so that it could be driven into the sediment through the water column to the maximum depth of sampling.
        - For the initial attempt, the sample tube will pushed manually into the sediment to the bottom of the deepest sample interval depth. A cap would then be placed on the top of the tube and the tube then extracted with a sediment core collected within the tube. If the sediment material appears to be loose and may release from the bottom of the coring tube, a cap will be affixed to the bottom of the core prior to lifting it out of the water.

    If the collected sediment is falls out the bottom of the coring tube and sample cannot be recovered, the sampling tube will be fitted with a sliding rubber piston to maintain suction in the tube while advancing the sampler, which better prevent softs sediment from escaping the coring tube during extraction.

        - Prior to advancing the core, a piston is placed into the sample tube and the seals will be checked to ensure a tight fit. The piston will be placed approximately 1-ft above the bottom of the sample tube.
        - The sample core tube will be lowered through the water column to the measured depth of the bottom. The line attached to the piston will be secured to allow the polycarbonate tube to slide past the piston as the tube is pushed into the sediment – the piston remains in place and does not move while the core tube advances into the sediment.
        - The tube is then pushed manually into the sediment until the bottom of the deepest sample interval depth or refusal.
        - The coring tube will then be pulled out of the sediment and lifted through the water column. As the bottom of the polycarbonate tube approached the water surface, a cap will be affixed to the bottom of the core prior to lifting the sample out of the water. After placing the bottom cap, the core will be positioned upright. Standing water preset above the piston will drained, the tube will be trimmed, the piston removed, and if necessary, another cap will be placed on the top of the tube.
        - Location ID, orientation, and total penetration depth will be recorded on the top cap. Cores will be transferred to the onshore work area in an upright position

    - Once the cores are transferred to the processing area, they will be left undisturbed momentarily to allow settling of suspended solids.
    - After the standing water above the sediment was visibly clear, holes will be drilled into the core tube to drain excess water above the sediment core. After the water is drained, the cores will be placed horizontally to allow for logging and processing.
    - Prior to processing the cores, additional aluminum foil or polyethylene sheeting will be placed on top of the work surface to prevent cross-contamination. If needed to access sediment from within the core tube, electric sheers will be used to cut open the core tube. Total recovery will be measured and the core will be the logged and photographed.
    - Prior to collecting the sediment samples from the core tube, the cores will be segregated into sample intervals representative of depth intervals required for sampling. The sample intervals will be based on recovery and the entire core will assumed to compact uniformly. (For example, if the core recovery was 75% of the total penetration, the top 6 inches of the sediment layer will be assumed to be the top 4.5 inches of sediment recovered in the core.) After calculating sample intervals based on recovery, cores will be sectioned and the sediment sampled.
  - b. If sediment is densely compacted or consists of a coarser sand and gravel (rather than cohesive organic material), and if the sediment can be removed to the maximum depth required without the cored hole collapsing prior to reaching that depth, a hand auger will be used.
  - c. If sediment is densely compacted or consists of a coarser sand and gravel and the sediment cannot be removed to the maximum depth required without the cored hole collapsing, the following will be attempted:
    - The 0-1 ft surface sediment sample will be collected either by hand using a hand auger or trowel. If the conditions do not allow collection by hand auger or trowel, an open-ended plastic cylinder will be driven into the ground surface to an approximate depth of 1 ft, which would isolate the sample area from surrounding loose wetland soils and preventing surface water from entering the excavation area. The sample was collected from inside the cylinder using a hand trowel.
    - After the initial surficial sample interval is collected, a 4 in. diameter section of Schedule 40 PVC pipe will be hand driven to the maximum sampling depth. Installation of the PVC pipe drive pipe will prevent the borehole from collapsing and prevented surface water and loose sediments present around the area of excavation from mixing with the samples collected from the depth intervals. Sediment will be sampled by removing the material from within the drive pipe using a hand auger.
- If sample locations are present within several feet of standing water and cannot be accessed safely on foot, a boat may be needed to facilitate sampling. Again, actual sampling equipment and techniques will be dependent on standing water depth, sediment type and sample depths. Sampling equipment and techniques described above may be used from a boat to collect sediment samples.

- If sample locations cannot be collected using hand methods described above (hand auger, trowel, core tube, etc.) either by foot or from a boat, a direct push (Geoprobe) boring rig or a vibracore rig will be used to access and sample the sediment.

Sediment samples will be composited over either 6-in or 1-ft depth intervals in a stainless-steel bowl or disposable aluminum pan. The volume of collected material will be stirred to homogenize the sample and then placed in appropriate glassware for submission to the laboratory.

Samples are planned to be submitted for laboratory analysis of chlorinated volatile organic compounds (CVOCs), uranium, copper, and total organic carbon (TOC). If the laboratory determines that the sample has less than 30% solids, a new sample will be collected with a greater sample volume, as necessary. In the field, if it appears the sample is overly wet, additional sample volume will be collected and submitted to the laboratory.

4. Implementation Procedures: Bog and Septic Field Investigations

4.1 BOG SEDIMENT INVESTIGATIONS

Up to 6 shallow hand probes will be advanced within the sphagnum bog to gather data related to the thickness of the peat/sediment material present. Specific data will be collected on the thickness and depths of the two distinct peat layers present in the Bog (the acrotelm and catotelm), and to determine characteristics of underlying (non-peat) material.

Prior to sampling at the Bog, each proposed sampling location will be located and reviewed for access and general field condition considerations. Due to the sensitive nature of the sphagnum bog material, additional access considerations will be determined, such as using wooden planks or plywood as temporary walkways to the sampling locations to spread contact pressure of the foot traffic.

A variety of hand probing and peat material sampling equipment may be used during the proposed bog explorations. Actual methods and equipment will be determined according to actual field conditions, peat consistency, depth and density, but may consist of the following:

- Solid, cylinder metal probing rods
- Liner-type sediment corer/sampler (e.g. Wildco or AMS)
- Small diameter peat probe (e.g. Wildco or AMS)
- Hand auger

Solid probes will first be advanced into the sphagnum bog peat material to evaluate if material types can be determined without needing to collect physical peat samples. If not successful with simple probing, other liner/coring type equipment will be used to collect the peat material for observations. If additional peat material is required for collection (see torvane test section below), a hand auger may be used to collect bulk material for analysis.

Additionally, up to 6 torvane tests may be performed in the shallow hand probes to evaluate the shear strength of the bog sediments if the material is suitable for a torvane test. It is possible that the peat will be too fibrous to obtain in-situ measurements.

It is anticipated that there is a sandy deposit below the peat material. To the extent possible this material will be sampled for geotechnical testing. Grain size distribution and hydrometer tests will be run on this material if adequate sample is recovered. The purpose of this testing is to evaluate the type of material to estimate either published strength or correlate this material with soils collected from borings along the containment wall alignment. It may be necessary to install temporary sheeting along the outside edge of the sediment excavation to minimize impact to the bog while removing the contaminated sediment. The bog is too sensitive to mobilize typical drilling equipment to determine in-situ strength characteristics of this underlying material.

4.2 FORMER SEPTIC FIELD TEST PITS

Following the geophysical survey at the former septic field area, up to 4 test pits will be excavated to confirm the presence and limits of the subsurface structures identified in the GPR and EM surveys. Test pits will be excavated to depths of approximately 8 to 10 feet using a track-mounted excavator.

Up to one soil analytical sample will be collected from the test pits at the former septic field to confirm the limits of the septic field structures. Soil samples will be collected from either a side walls of the test pit excavation, or from material excavated and placed adjacent to the excavation using a hand-held excavation device such as a shovel or hand trowel. Sample will be composited from a representative depth interval in a stainless-steel bowl or disposable aluminum pan. The volume of collected material will be stirred to homogenize the sample and then placed in appropriate glassware for submission to the laboratory.

Samples are planned to be submitted for laboratory analysis of VOCs, PCBs, semi-volatiles (including, polycyclic aromatic hydrocarbons (PAHs) (benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, and indeno(1,2,3-cd)pyrene), Metals (including arsenic, uranium, thorium, barium, chromium, cobalt, copper, iron, manganese, and molybdenum), Nitrate-N, and Nitrite-N.

5. Implementation Procedures: Non-sampling Field Work/Survey

5.1 GEOPHYSICAL SURVEY

Geophysical surveys will be completed in two areas of the site; within the landfill area and within the former septic system area north of the Cooling Pond. A geophysical survey was performed by MACTEC at the landfill in conjunction with the Remedial Investigation (RI) but was only performed within the limits of the fencing at the time of the survey and identified some anomalies which may have been due to the metal fencing. This PDI will confirm the results of a geophysical survey previously performed at the landfill documented in the RI report, and extend the survey to outside the limits of the fence. The fence will be removed, and some vegetation may need to be cleared prior to the survey.

The second geophysical survey will be performed within the former septic fields to confirm the limits of the septic fields, and to evaluate if there are other buried debris or associated structures in the area. The former septic field area is currently paved with a driveway and parking lot.

The surveys will be completed by establishing a 10-foot by 10-foot reference grid within each survey area to be marked using spray paint or flagging. Perpendicular nodes will also be laid out with a theodolite or fiberglass measuring tape throughout the survey areas.

At each location, two methodologies will be used in the geophysical survey. An electromagnetic (EM) survey will be used to evaluate for debris. The EM survey is capable of detecting metal debris at depths of approximately up to 8 feet. EM devices proposed to be used in the survey include Radiodetection Model 7100, Genoics EM61, or Genoics EM31. Conductivity is logged in 0.5-second increments as the operator traverses the grid and annotates the data files. A Ground Penetrating Radar (GPR) survey will also be used, which is capable of identifying subsurface structures in greater detail at depths of up to approximately 15 feet. GPR devices proposed to be used in the survey include GSSI Model SIR-2000 or SIR-4000, with a 200 or 400 MHz radar antenna.

In addition to the EM and GPR surveys at the landfill, a total-field magnetic profiling is planned to distinguish any anomalies caused by ferrous metal or non-ferrous metal objects. The total-field profiling is performed with a Geometrics model G-858 magnetometer, which records magnetic data values at 0.5 seconds as the operator traverses the 10-feet grid

5.2 WETLAND CHARACTERIZATION

This PDI will collect the information needed to characterize current conditions at the Cooling Pond and the Bog in order to design the wetland restoration plan following the remedial excavations in each area. This investigation includes compiling an inventory of plant species growing within the habitat zones, and delineation of resource areas and habitat types, including vegetated border areas, banks, and transitional zones which may be disturbed during remedial activities. Observations will be documented on the dominant and common species within each habitat zone and supporting figures and field notes will be annotated with current conditions.

The wetlands mapping and evaluation of the functions and values will be conducted as follows:

- Wetlands will be delineated according to the methodology required per 310 CMR 10.00 as described in *Delineating Bordering Vegetated Wetlands Under the Massachusetts Wetlands Protection Act* (MassDEP, 1995).
- Wetland functions and values will be assessed according to the methodology described in *The Highway Methodology Workbook Supplement: Wetland Functions and Values – A Descriptive Approach* (U.S. Army Corps of Engineers, New England District, September 1999).

Data from the bog sediment depths will be used with species inventory and delineation information collected in this activity to develop a final restoration approach, including soil specifications, planting plan, and related details.