Addendum E

Final Remedial Action Plan
DOE-EM/GJ1547
July 2008

Remedial Action Inspection Plan (RAIP)

Number	Title	
Document	Remedial Action Inspection Plan (RAIP)	
Attachment 1	Computer Aided Earthmoving System (CAES) For Landfills	

ADDENDUM E – REMEDIAL ACTION INSPECTION PLAN (RAIP)

STATEMENT OF POLICY

This Remedial Action Inspection Plan identifies the means by which the remedial action activities associated with the disposal cell at Crescent Junction, Utah are controlled, verified, and documented. This plan has been developed within the scope of the Energy*Solutions* Quality Assurance Plan and complies with the applicable parts of American Society of mechanical engineers (ASME) NQA-1-2000, *Quality Assurance Program for Nuclear Facilities*, Title 10, *Code of Federal Regulations* (CFR) 830 Subpart A, *Quality Assurance*, and DOE O 414.1C, *Quality Assurance.*

The procedures defining Organization, QC Personnel Qualification & Certification, Quality Assurance Records Control, Control of Measuring and Test Equipment, and Conditions Reports are in accordance with the applicable section of the Quality Assurance Plan as follows: Organization – Section 1, Organization, QC Personnel Qualification & Certification – Section 2, Quality Assurance Program, Quality Assurance Records Control – Section 17, Quality Assurance Records, Control of Measuring and Test Equipment – Section 12, Control of Measuring and Testing Equipment, and Conditions Reports - Sections 15, Nonconforming Materials, Parts or Components and Section 16, Corrective Action.

This Remedial Action Inspection Plan and the Quality Assurance Plan describe the means by which EnergySolutions will ensure that the Environmental Protection Agency's requirements which have the concurrence of the U.S. Nuclear Regulatory Commission (NRC) and the selected remedial action guidelines for Testing and Inspection Plans During construction of DOE's *Remedial Action Plan and Site Design for Stabilization of Moab Title I Uranium Mill RRM at the Crescent Junction, Utah, Disposal Site (RAP)* are satisfied.

TITLE: TESTING AND INSPECTION

1.0 PURPOSE

To describe the methods by which the construction activities will be tested and inspected to verify compliance with the Design Specification requirements.

2.0 SCOPE

This procedure defines the testing and inspection of remedial action construction activities at Crescent Junction, Utah. Types of tests, test frequencies and acceptability, and documentation and reporting requirements are contained in this procedure. Procedures for performing the individual tests shall be in accordance with the applicable ASTM Standards, the referenced or other approved methods and the Design Specifications.

3.0 DEFINITIONS

ASTM American Society for Testing and Materials

CAES Computerized Aided Earthmoving System

GPS Global Positioning System

RRM Residual Radioactive Material

4.0 ATTACHMENTS

CAES Brochure

5.0 REFERENCES

1. ASTM C 117 – Standard Test Method for Materials Finer than 75 µm (No. 200) Sieve in Mineral Aggregates by Washing
2. ASTM C-136 – Test Method for Sieve Analysis of Fine and Course Aggregates
3. ASTM D 422 – Particle-Size Analysis of Soils
4. ASTM 698 – Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/cu ft)
5. ASTM D 1140 – Amount of Material in Soils Finer than the No. 200 (75-micrometer) Sieve.
6. ASTM D 1556 – Density and Unit Weight of Soil in Place by the Sand-Cone Method
7. ASTM D 2216 – Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
8. ASTM D 4318 – Liquid Limit, Plastic Limit, and Plasticity Index of Soils

9. ASTM D 4643 – Determination of Water (Moisture) Content of Soil by the Microwave Oven Heating
10. ASTM D 4944 – Field Determination of Water (Moisture) Content of Soil by the Calcium Carbide Gas Pressure Tester.
11. ASTM D 4959 – Determination of Water (Moisture) Content of Soil by Direct Heating Method.
12. ASTM D 6938, In-Place Density and Water content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)
13. 10 CFR 50 Appendix B
14. Computerized Aided Earthmoving System (CAES) Office User Guide
15. Energy*Solutions* Quality Assurance Plan
16. Energy*Solutions* QA/QC Work Procedures
17. Crescent Junction Design Specifications

6.0 GENERAL REQUIREMENTS

6.1 GENERAL APPROACH TO SOIL COMPACTION AND COMPACTION TESTING

Typically, soil is tested in a laboratory to determine the maximum density that the particular soil can achieve. The maximum density will be achieved at the optimum moisture content for that soil. The laboratory maximum density and optimum moisture content for the soil becomes the basis of comparison for the compaction of the soil in the field.

In the field, the soil is placed in layers, compacted with specialized compaction equipment, and tested to confirm that the soil density is close to the previously determined laboratory maximum density. A variety of field tests have been used to determine soil density, including sand cone, rubber balloon, drive cylinder and nuclear gauge methods. Moisture content tests are also needed to determine the in-place soil density. All of these test methods determine the density of a small quantity of soil at a single point in a large quantity of placed and compacted soil. A number of tests are required to infer that an entire layer of soil is adequately compacted. The documentation of soil compaction has typically consisted of a visual inspection report combined with a map of the compacted layer and the field test results.

6.1.1 Computer Aided Earthmoving System (CAES)

GPS and computer terrain modeling technology have been combined to provide a new method of performing soil compaction. The equipment is called Computer Aided Earthmoving System (CAES). The system works as follows:

- A digital terrain model of the site to receive fill material is fed into an on-site computer linked to a computer in the cab of the compaction equipment. A GPS receiver is also linked to the compaction machine’s on-board computer. When the machine moves across the site, the GPS equipment provides the exact position and elevation of the equipment at all times.

- Soil is dumped and spread into a layer of fill. As the compaction machine spreads and compacts the layer of soil, the position of the machine is compared to the original terrain model to determine the location and thickness of the fill layer being installed. The on-board computer assists the equipment operator to place the material in a layer with uniform thickness by informing the operator of thick or thin areas of the fill.
- After a layer has been placed with uniform thickness, the compaction equipment makes multiple passes over the fill to compact the fill. A compaction machine, compacting material at the correct moisture content, will eventually compact the fill to near its maximum density such that additional compaction passes produce negligible change. The computer recording the GPS location data interprets the passes that produce no vertical change to indicate that the soil is at its maximum density.
- A record of each soil layer's location, thickness, and compaction is generated by the computer.

Visual inspection, correct placement and compaction techniques, and good moisture control are still required to ensure that fill is properly placed, but the CAES method has distinct advantages over traditional field density testing. Lift thicknesses are computer controlled and are more uniform than when layers are installed based on visual estimates by the equipment operators. The computer checks compaction over the entire surface of every layer, whereas the in-place test methods only check a few points on each layer. See Attachment 1 for vendor data on the CAES system.

Soil density verification tests and independent land surveys will be performed to demonstrate the effectiveness of the CAES System. In the following sections of this plan, the verification testing and surveying will be described in detail for each element of the cell in which fill is placed.

6.2 CELL EXCAVATION

Part of the proposed waste cell will be below the ground surface in an excavation. The excavation will be constructed in phases with interim dikes that will be removed as operations require or as subsequent phases are constructed. The overall cell floor and side slopes are as described below.

6.2.1 Floor and side slopes

The cell floor slopes 2.3% from northwest to southeast. The cut slopes on the north, west, and south sides of the cell slope at 2:1.

6.2.2 Final floor and embankment elevations

The cell floor coordinates and elevations are shown on the design plans. When each section of the cell is excavated to the elevations indicated on the plans, a verification survey shall be performed to confirm that the excavation is to the proposed lines and grades. The verification survey shall be signed by the Contractor and submitted to Construction Manager.

6.2.3 Floor of cell is in the weathered Mancos Shale

The cell floor elevation has been set based on test pit and soil boring data and is at least two feet below the top of the Mancos Shale at each data point. The cell floor shall be visually inspected to confirm that it is in the Mancos Shale formation. If an area is observed where the overburden soil extends below the cell floor, the area will be undercut, backfilled with prepared Mancos Shale, and compacted.

6.2.4 Inspection and Testing

The Quality Control (QC) Inspector shall visually inspect the material and ground preparation. The QC Inspector shall verify that the cell floor is constructed in accordance with Plans and Specifications by checking and confirming:

- Floor and side slopes are per the design plans;
- Final floor and side slopes survey match the coordinates and elevations in the plans; and
- The floor is weathered Mancos Shale or low spots have been compacted with Mancos Shale.

6.3 EMBANKMENT CONSTRUCTION

Part of the proposed waste cell will be below the existing ground surface in an excavation and part will be above the existing ground surface within a constructed embankment. The proposed embankment will have 3:1 interior slopes, 5:1 exterior slopes, and a 30 ft wide level top. Excavated material from the cell excavation will be used to construct the waste cell perimeter embankment.

6.3.1 Material

Excavated material from the cell excavation shall be segregated into four types of soil, topsoil, weathered Mancos Shale, common fill, and unsuitable material. Materials shall be stockpiled separately. The perimeter and spoil embankments will be constructed of common fill. The fill shall be tested to determine its maximum dry density in accordance with ASTM D 698 and the moisture content shall be modified to bring the fill to its optimum moisture for compaction.

6.3.2 Ground Preparation

The ground beneath the proposed perimeter and spoil embankments shall be prepared by stripping vegetation and loose soil from the site, scarifying and compacting the top six inches of soil.

6.3.3 Lift Placement and Thickness

The embankment shall be constructed of fill materials placed in continuous and approximately horizontal lifts. The method of dumping and spreading fill shall result in loose lifts of nearly uniform thickness, not to exceed 12". At the Contractor's option, the compactor may be equipped with a Computer Aided Earthmoving System and soil placement and compaction shall be controlled by the CAES. The contractor may use the CAES to determine and document compaction, or perform soil density tests in accordance with the Inspection and Testing, section below.

6.3.4 Inspection and Testing Waste Cell Perimeter Embankment

The Quality Control (QC) Inspector shall visually inspect the material preparation, ground preparation, and fill placement operations. The QC Inspector shall perform in-place density tests with companion moisture tests to verify at least 95% of the laboratory maximum dry density in accordance with ASTM D 698 Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort. The QC Inspector shall verify that the perimeter embankment is constructed in accordance with Plans and Specifications by checking and confirming:

- Interior slopes are 3:1, and exterior slopes are 5:1 and a 30 ft wide level top verified one time at the end of excavation;
- Fill material is properly moisture conditioned near optimum moisture.
- Fill material is placed in continuous and approximately horizontal lifts. The method of dumping and spreading material shall result in loose lifts of nearly uniform thickness, not to exceed 12".
- Embankment construction soil is common fill;
- Compaction is properly performed.
- Compaction – Embankment fill shall be compacted with a minimum 45,000 lb static weight compactor. The compactor shall be a footed roller capable of kneading compaction, with feet a minimum of 6 inches in length.
- Compaction Verification Tests – Perform in-place density and moisture content tests on compacted fill material in accordance with the In-Place Density Testing sections below.
- Verification tests of in-place density shall be performed on initial layers of soil placed, and on any specific type of material in which the CAES is used.

Testing and verification frequencies for lifts constructed without the CAES system shall be in accordance with the following:

Testing of Waste Cell Perimeter Embankment

- For material compacted by other than hand-operated machines: One test per 50,000 square feet or 1,850 cubic yards of material placed, or fraction thereof, a minimum of one test for each lift of fill or backfill, and a minimum of two tests per day that fill is compacted in accordance with ASTM D 6938.
- One test per 500 square feet, or fraction thereof, of each lift of fill or backfill areas for material compacted by hand-operated machines.

In place density and moisture content tests shall be performed in accordance with the following methods:

- ASTM D 1556 – Density and Unit Weight of Soil in Place by the Sand-Cone Method
- ASTM D 2216 – Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
- ASTM D 6938 - In-Place Density and Water content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)
- ASTM D 4643 - Determination of Water (Moisture) Content of Soil by the Microwave Oven Heating

Check Tests on In-Place Densities

If ASTM D 6938 is used, check in-place densities by ASTM D 1556 as follows:

- One check test for each 20 tests per ASTM D 6938, of fill or backfill compacted by other than hand-operated machines.
- One check test for each 20 tests per ASTM D 6938, of fill or backfill compacted by hand-operated machines.

  - ***Optimum Moisture and Laboratory Maximum Density***

  Perform Laboratory Density and Moisture Content tests (ASTM D 698 and ASTM D 2216) for each type of fill material to determine the optimum moisture (optimum moisture content plus or minus 5%) and laboratory maximum density values. One representative density test per material type and every 20,000 cubic yards there after or when any change in material occurs which may affect the optimum moisture content or laboratory maximum dry density. One correlation test for moistures every 10 tests per ASTM 6938 will be performed in accordance to ASTM D 4643 or ASTM D 2216.In the stockpile, excavations, or borrow areas, perform moisture tests to control the moisture content of material being placed as fill. Control of moisture content of fill shall be performed by conducting routine testing of moisture content by one of the following tests:

    - ASTM D 2216 - Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass (Oven Moisture)

- ASTM D 4643 - Determination of Water (Moisture) Content of Soil by the Microwave Oven Heating
- ASTM D 4944 - Field Determination of Water (Moisture) Content of Soil by the Calcium Carbide Gas Pressure Tester
- ASTM D 4959 - Determination of Water (Moisture) Content of Soil by Direct Heating

During unstable weather, perform tests as dictated by local conditions and approved by the Construction Manager.

6.3.5 Waste Cell Spoil Material Embankment (Wedge)

The Waste Cell Spoil Material Embankment is a fill embankment to be constructed north of the waste cell. The embankment will divert storm water from the Book Cliffs around the waste cell, and shall be constructed of surplus excavated material (spoil material) from the waste cell excavation. Prior to placement, spoil material shall be tested to determine its maximum dry density in accordance with ASTM D 698, Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort, and the moisture content shall be modified to bring the fill to near optimum for compaction.

Construct the Waste Cell Spoil Material Embankment as follows:

1) Prepare the ground beneath the proposed perimeter embankment by stripping vegetation and loose soil from the site.
2) Dump and spread fill in loose lifts of nearly uniform thickness, not to exceed 12”. Compact material with rollers, equipment tracks, or successive passes of scrapers. Fill shall be compacted to a density of 90% of the laboratory determined maximum density in accordance with ASTM D 698.

The QC Inspector shall verify that the spoil embankment is constructed in accordance with Plans and Specifications by checking and confirming:

- Exterior slopes are 3:1,
- Fill material is properly moisture conditioned near optimum moisture.
- Fill material is placed in continuous and approximately horizontal lifts. The method of dumping and spreading material shall result in loose lifts of nearly uniform thickness, not exceed 12”
- Embankment construction soil is common fill;
- Compaction is properly performed.
- Compaction – Embankment fill shall be compacted with a minimum 45,000 lb static weight compactor. The compactor shall be a footed roller capable of kneading compaction, with feet a minimum of 6 inches in length.
- Compaction Verification Tests – Perform in-place density and moisture content tests on compacted fill material in accordance with the In-Place Density Testing sections below.
- Verification tests of in-place density shall be performed on initial layers of soil placed, and on any specific type of material in which the CAES is used.

Testing and verification frequencies for lifts constructed without the CAES system shall be in accordance with the following:

Testing of Waste Cell Spoil Material Embankment

- One test per 100,000 square feet or 3,700 cubic yards of material placed for material compacted by other than hand-operated machines
- One test per 500 square feet, or fraction thereof, of each lift of fill or backfill areas for material compacted by hand-operated machines

In place density and moisture content tests shall be performed in accordance with the following methods:

- ASTM D 1556 – Density and Unit Weight of Soil in Place by the Sand-Cone Method
- ASTM D 2216 – Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
- ASTM D 6938 - In-Place Density and Water content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)
- ASTM D 4643 - Determination of Water (Moisture) Content of Soil by the Microwave Oven Heating

Check Tests on In-Place Densities

If ASTM D 6938 is used, check in-place densities by ASTM D 1556 as follows:

- One check test for each 20 tests per ASTM D 6938, of fill or backfill compacted by other than hand-operated machines.
- One check test for each 20 tests per ASTM D 6938, of fill or backfill compacted by hand-operated machines.

Optimum Moisture and Laboratory Maximum Density

Perform Laboratory Density and Moisture Content tests (ASTM D 698 and ASTM D 2216) for each type of fill material to determine the optimum moisture (optimum moisture content plus or minus 5%) and laboratory maximum density values. One representative density test per material type and every 20,000 cubic yards there after or when any change in material occurs which may affect the optimum moisture content or laboratory maximum dry density. One correlation test for moistures every 10 tests per ASTM 6938 will be performed in accordance to ASTM D 4643 or ASTM D 2216.

In the stockpile, excavations, or borrow areas, perform moisture tests to control the moisture content of material being placed as fill. Control of moisture content of fill shall be performed by conducting routine testing of moisture content by one of the following tests:

- ASTM D 2216 - Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass (Oven Moisture)

- ASTM D 4643 - Determination of Water (Moisture) Content of Soil by the Microwave Oven Heating
- ASTM D 4944 - Field Determination of Water (Moisture) Content of Soil by the Calcium Carbide Gas Pressure Tester
- ASTM D 4959 - Determination of Water (Moisture) Content of Soil by Direct Heating
- During unstable weather, perform tests as dictated by local conditions and approved by the Construction Manager.

6.4 RESIDUAL RADIOACTIVE MATERIAL (RRM)

The objective is to place and compact the RRM in the waste cell to create a stable waste mass. The QC Inspector shall visually inspect the material preparation, ground preparation, and RRM placement operations, and shall perform in-place density tests with companion moisture tests for the CAES to verify that RRM compaction meets the compaction requirements. The QC Inspector shall verify that the RRM placement is performed in accordance with Plans and Specifications, and that the top of the placed waste matches the final grades identified in Section 6.4.5. RRM shall not be placed when frozen or over frozen subgrade. If rain water ponding has occurred, placement of RRM waste shall only be performed after the area is dewatered and approval of Construction Manager, QC Inspector or designee to place is obtained.

6.4.1 Moisture Modification

RRM material should be shipped from Moab at or near optimum moisture for compaction. Some RRM may require minor moisture modification when received at Crescent Junction.

6.4.2 RRM Placement

Scarify the top one inch of subsoil or preceding RRM lift using a footed roller or a dozer prior to placement of subsequent RRM layers. Fill materials shall be placed in continuous and approximately horizontal lifts. The method of dumping and spreading RRM shall result in loose lifts of nearly uniform thickness, not to exceed 12”. Compaction equipment shall consist of footed rollers or dozers. Footed rollers shall have a minimum weight of 45,000 pounds and at least one tamping foot shall be provided for each 110 square inches of drum surface. The length of each tamping foot from the outside surface of the drum shall be at least 6 inches. During compaction operations, the spaces between the tamping feet shall be maintained clear of materials which would impair the effectiveness of the tamping foot rollers. Dozers shall have a minimum ground pressure of 1,650 lbs per sq ft. The CAES shall be used to direct fill placement, monitor compaction, and record the location and thickness of each soil layer being placed.

6.4.3 Inspection and Testing

The Quality Control (QC) Inspector shall visually inspect the ground preparation and fill placement operations. RRM shall be compacted to meet 90% of the laboratory determined maximum dry density as determined by (ASTM D 698). The QC Inspector shall verify that the RRM placement is constructed in accordance with Design Plans and Specifications by checking and confirming:

- Assessment tests shall be performed on RRM to assure compliance with specified requirements and to develop compaction requirements for placement. A minimum of three tests for maximum dry density (ASTM D 698) and optimum moisture content (optimum moisture plus or minus 3%) (ASTM D 2216) shall be performed for each type of RRM soil observed.
- Fill material is properly moisture conditioned, one moisture content quick test will be performed each day material is placed in accordance with (ASTM D 4643, ASTM D 4944, or ASTM D 4959) until a sufficient number have been performed to demonstrate a clear correlation allowing a reduction in testing.
- Fill material is placed in continuous and approximately horizontal lifts. The method of dumping and spreading RRM shall result in loose lifts of nearly uniform thickness, not to exceed 12".
- Compaction meets specifications.
- Compaction by CAES – the QC inspector shall monitor CAES compaction by visually inspecting the process and reviewing the computer records for each layer of soil placed.
- Verification tests of in-place density shall be performed on the initial layer of RRM and on any layers in which the CAES indicates that problems occurred obtaining compaction. In-place density will be taken every six months to verify the performance of the CAES.

Note: Companion sand cone tests and oven moisture tests must be performed along with nuclear tests until a sufficient number have been performed to demonstrate a clear correlation.

If CAES is not used the following testing requirements shall be followed:

- Compaction Verification Tests – Perform in-place density and moisture content tests on compacted fill material in accordance with the following requirements:
    - When verification a representative sample from each principal type or combination of blended RRM materials shall be tested to establish compaction curves using ASTM D 698. A minimum of one set of compaction curves shall be developed per 10,000 cubic yards of RRM material. In-place density and moisture content tests are performed on a soil layer; a minimum of two tests shall be performed per 5,000 cubic yards of fill material placed.

- Compaction and moisture content tests shall be performed in accordance with the following methods:
    - ASTM D 1556 - Density and Unit Weight of Soil in Place by the Sand-Cone Method
    - ASTM D 2216 - Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass (Oven Moisture)
    - ASTM D 6938 - In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)
    - ASTM D 4643 - Determination of Water (Moisture) Content of Soil by the Microwave Oven Heating
- After lift placement, moisture content shall be maintained until the next lift is placed.
- Erosion that occurs in the RRM layers shall be repaired and grades re-established.
- Freezing and desiccation of the RRM soil shall be prevented. If freezing or desiccation occurs, the affected soil shall be reconditioned as directed.
- Areas that have been repaired shall be retested as directed. Repairs to the RRM layers shall be documented including location and volume of soil affected, corrective action taken, and results of retests.

6.4.4 Demolition Debris

Demolition debris will be placed in the waste cell along with RRM material. Each container of demolition debris shall be spread in a single layer, not stacked, and placed in a manner that results in a minimum of voids around the debris. The following materials will be placed in the waste cell:

- Wood, Concrete, Masonry: Cut or break up to a maximum 3-foot size measured in any dimension.
- Structural Steel Member, Pipes, Ducts, Other Long Items: Cut into maximum 10-foot lengths.
- Concrete, Clay Tile, and Other Pipes: Crush concrete and clay tile pipes. Crush other pipes and ducts that are 6 inches or greater in diameter or, if crushing is impractical, cut pipes and ducts in half longitudinally. Do not crush asbestos-cement pipe.
- Rubber Tires Excavated at the Site: Cut into two halves around the circumference.
- Geomembranes and Other Sheet Material: Cut into strips a maximum of 4 feet wide by 4 feet long.
- Tree Limbs 4 inches in Diameter and Larger: Cut into lengths of 8 feet or less.

6.4.5 Final RRM Geometry

The top surface of the RRM shall be no greater than 2 inches above the lines and grades shown on the drawings and verified by survey or the use of the CAES. No minus tolerance will be permitted.

6.5 INTERIM COVER

After a section the RRM have been placed in the waste cell to final grade and verified by survey, an interim cover consisting of 1 ft of clean, compacted soil shall be placed over the RRM. Interim cover material will be placed and compacted directly on top of RRM to provide a buffer of uncontaminated soil prior to the placement of the final multi-layer cap.

6.5.1 Material

Interim Cover Soil will be soil from the excavation of the Crescent Junction waste cell. It will be material that has been produced on site by modifying the existing overburden soil and weathered Mancos Shale excavated on site. Overburden and weathered Mancos Shale shall be excavated, pulverized, wetted, and mixed to produce a uniform fine-grained soil near optimum moisture content for compaction. Soil shall be free of roots, debris, organic or frozen material, and shall have a maximum clod size of 2 inch based on visual at the time of compaction.

6.5.2 Ground Preparation

The RRM beneath the proposed interim cover shall be prepared by scarifying to a depth of one inch prior to the placement of the initial lift of interim cover soil.

6.5.3 Lift Placement and Thickness

The interim cover shall be constructed of fill materials placed in continuous lifts of uniform thickness. The method of dumping and spreading Interim Cover Soil over shall result in loose lifts not to exceed 12”. The CAES shall be used to direct fill placement, monitor compaction, and record the location and thickness of each soil layer being placed.

6.5.4 Inspection and Testing

The Quality Control (QC) Inspector shall visually inspect the ground preparation and fill placement operations. Interim Cover Layer shall be compacted to meet 90% of the laboratory determined maximum dry density as determined by (ASTM D 698). The QC Inspector shall verify that the interim cover is constructed in accordance with Plans and Specifications by checking and confirming:

- Interim Cover is properly moisture conditioned, one moisture content test will be performed each day material is placed in accordance with (ASTM D 4643, ASTM D 4944, or ASTM D 4959);
- Interim Cover is placed in continuous and approximately horizontal lifts. The method of dumping and spreading interim cover shall result in loose lifts of nearly uniform thickness, not to exceed 12”.
- Compaction is properly performed.

- Compaction by CAES – the QC inspector shall monitor CAES compaction by visually inspecting the process and reviewing the computer records for each layer of soil placed.
- Compaction Verification Tests – Perform in-place density and moisture content tests on compacted fill material in accordance with the following requirements:
    - Verification tests of in-place density shall be performed on the first 5,000 cubic yards of Interim Cover and on any layers in which the CAES indicates that problems occurred obtaining compaction.
    - When verification in-place density and moisture content tests are performed on a soil layer, a minimum of two tests shall be performed per 5,000 cubic yards of fill material placed.
    - Compaction and moisture content tests shall be performed in accordance with the following methods:
        - ASTM D 1556 - Density and Unit Weight of Soil in Place by the Sand-Cone Method
        - ASTM D 2216 - Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass (Oven Moisture)
        - ASTM D 6938 - In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)
        - ASTM D 4643 - Determination of Water (Moisture) Content of Soil by the Microwave Oven Heating

Note: Companion sand cone tests and oven moisture tests must be performed along with nuclear tests until a sufficient number have been performed to demonstrate a clear correlation.

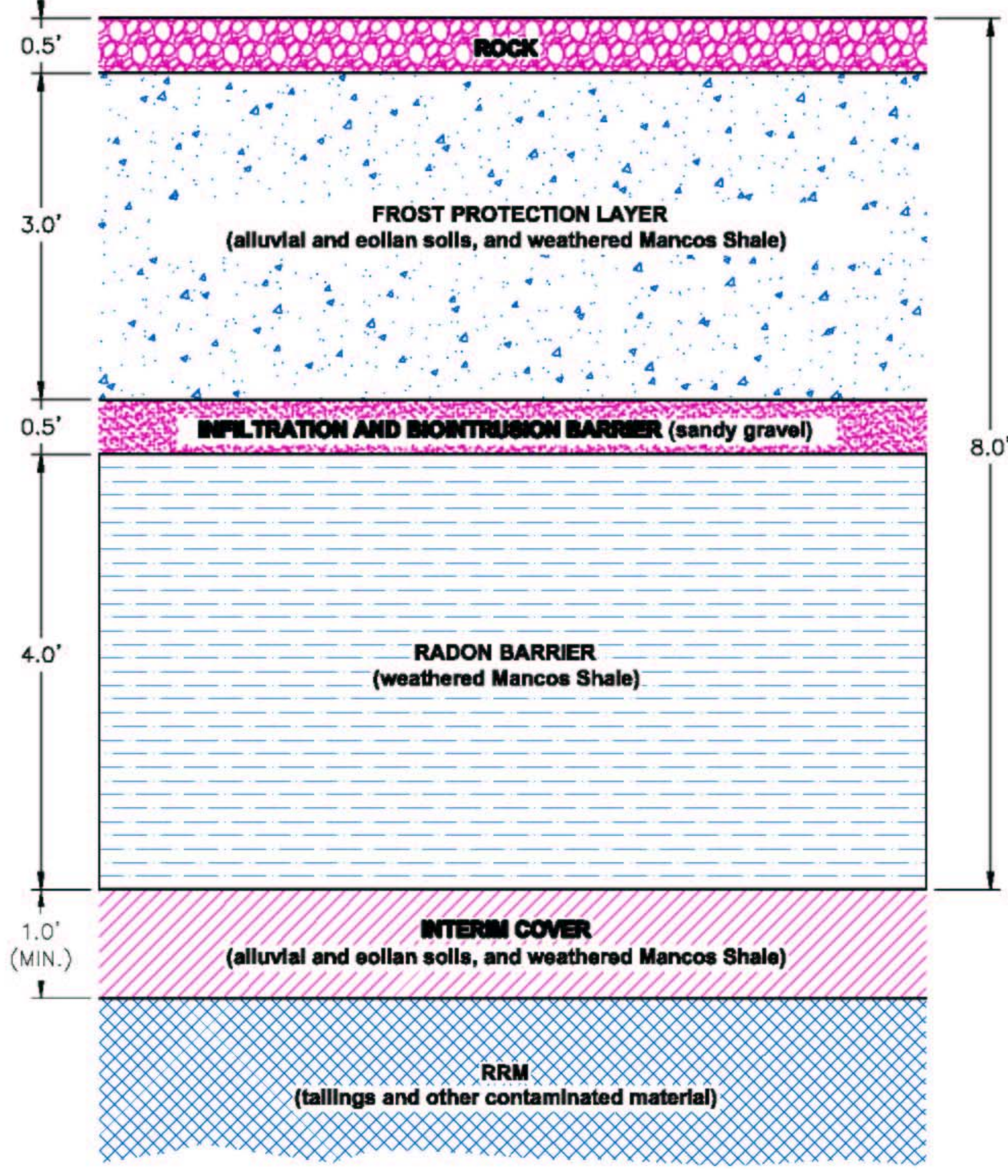
- After lift placement, moisture content shall be maintained until the next lift is placed.
- Erosion that occurs in the Interim Cover layer shall be repaired and grades re-established.
- Freezing and desiccation of the Interim Cover soil shall be prevented. If freezing or desiccation occurs, the affected soil shall be reconditioned as directed.
- Areas that have been repaired shall be retested as directed. Repairs to the Interim Cover layer shall be documented including location and volume of soil affected, corrective action taken, and results of retests.

6.5.5 Final Interim Cover Geometry

Proof roll the interim cover with rubber-tired construction equipment, such as a loaded dump truck or loaded scraper, with a minimum weight of 45,000 lbs to produce a smooth compacted surface on the top of the completed interim cover layer, such that direct rainfall causes minimal erosion. The top surface of the Interim Cover shall be no greater than 2 inches above the lines and grades shown on the drawings. No minus tolerance will be permitted

6.6 CAP CONSTRUCTION

An UMTRA cover, a multi-layer cap, will be constructed over the RRM waste and interim cover. The cap materials and configuration are intended to protect the RRM waste from exposure due to water erosion, wind erosion, and burrowing animals for a design-life of 1,000 years. The proposed cap layers are shown in the following figure:



UMTRA COVER DESIGN

6.7 RADON BARRIER LAYER

The initial cap layer is a 4 ft thick Radon Barrier Layer constructed of compacted clay soil. The Radon Barrier will be a low-permeability clay layer that limits radon emissions from the RRM and limits the infiltration of water from above.

6.7.1 Material

The Radon Barrier Layer will be constructed of processed Mancos Shale soil. The clay soil will be produced on site by processing excavated Mancos Shale into a fine-grained soil and adding water to bring the Mancos Shale soil to near optimum moisture content for compaction.

Assessment tests shall be performed on radon barrier material to assure compliance with specified requirements and to develop compaction requirements for placement. A minimum of three tests for maximum dry density (ASTM D 698), optimum moisture content (ASTM D 2216) shall be performed for each type of soil observed to establish the optimum moisture for radon barrier material placement. Mancos Shale soil produced for Radon Barrier fill shall be tested to determine its maximum dry density and the optimum moisture content. The moisture content shall be modified to bring the fill to optimum for compaction. As a minimum, perform the following soil tests on each 10,000 cu yds of soil:

ASTM D 4318, Liquid Limit, Plastic Limit, and Plasticity Index of Soils
ASTM D 1140, Amount of Material in Soils Finer than the No. 200 Sieve
ASTM D 422, Standard Test Method for Particle-Size Analysis in Soil
ASTM D 698, Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort.
ASTM D 2216, Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass and/or ASTM D 4643, Determination of Water (Moisture) Content of Soil by the Microwave Oven Heating

6.7.2 Ground Preparation

The interim cover layer beneath the proposed Radon Barrier Layer shall be prepared by scarifying to a depth of one inch prior to the placement of the initial lift of Radon Barrier soil.

6.7.3 Lift Placement and Thickness

The Radon Barrier shall be constructed of fill materials placed in continuous lifts of uniform thickness. The method of dumping and spreading radon barrier shall result in loose lifts not to exceed 12". The CAES shall be used to direct fill placement, monitor compaction, and record the location and thickness of each soil layer being placed. Compaction equipment shall consist of footed rollers which have a minimum weight of 45,000 pounds and at least one foot for each 110 square inches of drum surface. The length of each tamping foot shall be at least 6 inches, from the outside surface of the drum. During compaction operations, the spaces between the tamping feet shall be maintained clear of materials which would impair the effectiveness of the tamping foot rollers.

6.7.4 Inspection and Testing

The Quality Control (QC) Inspector shall visually inspect the processing of Mancos Shale into clay soil, ground preparation, and fill placement operations. The QC Inspector shall perform in-place density tests with companion moisture tests (optimum moisture plus or minus 3%) to verify that the CAES compaction results in a density of at least 95% of the material's maximum dry density according to ASTM D 698 Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort. The QC Inspector shall verify that the Radon Barrier is constructed in accordance with Plans and Specifications by checking and confirming:

- Fill material is properly moisture conditioned, one moisture content test will be performed each day material is placed in accordance with (ASTM D 4643, ASTM D 4944, or ASTM D 4959);
- Material is placed in continuous uniform thickness lifts. The method of dumping and spreading radon barrier shall result in loose lifts not to exceed 12".
- Radon Barrier soil is processed Mancos Shale;
- Tests have been performed on the processed shale soil to determine its maximum dry density and optimum moisture content.
- Compaction – Radon Barrier fill is spread and compacted with a footed roller. The compactor shall be equipped with a Computer Aided Earthmoving System and soil placement and compaction shall be controlled by the CAES.
- Compaction by CAES – the QC inspector shall monitor CAES compaction by visually inspecting the process and reviewing the computer records for each layer of soil placed.
- Compaction Verification Tests – Perform in-place density and moisture content tests on compacted fill material in accordance with the following requirements:
    - Verification tests of in-place density shall be performed on initial layer of radon barrier placed, and on any layers in which the CAES indicates that problems occurred obtaining compaction.
    - When verification in-place density and moisture content tests are performed on a soil layer, a minimum of one test shall be preformed a minimum of 2 tests per 5,000 cubic yards of material placed.
    - Compaction and moisture content tests shall be performed in accordance with the following methods:
        - ASTM D 1556 – Density and Unit Weight of Soil in Place by the Sand-Cone Method

- ASTM D 2216 – Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
- ASTM D 6938 - In-Place Density and Water content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth
- ASTM D 4643 - Determination of Water (Moisture) Content of Soil by the Microwave Oven Heating

Note: Companion sand cone tests and oven moisture tests must be performed along with nuclear tests until a sufficient number have been performed to demonstrate a clear correlation.

- After placement, moisture content shall be maintained or adjusted to meet criteria.
- Erosion that occurs in the fill layers shall be repaired and grades re-established.
- Freezing and desiccation of the Radon Barrier layer shall be prevented. If freezing or desiccation occurs, the affected soil shall be removed or reconditioned as directed.
- Areas that have been repaired shall be retested as directed. Repairs to the Radon Barrier layer shall be documented including location and volume of soil affected, corrective action taken, and results of retests.

6.7.5 Initial and Confirmatory Surveys

Verification of the thickness of the Radon Barrier Layer will be performed by comparing before and after surveys of the Layer by surveying or using CAES. Prior to placement of the Radon Barrier Layer, an initial survey shall be performed of the section to be capped. The initial survey will document the pre-cap geometry of the site. After the Radon Barrier Layer has been installed, a post-installation survey will be performed on the top of the Radon Barrier fill to confirm that the total fill thickness is in accordance with the plans and specifications.

6.8 INFILTRATION AND BIOINTRUSION BARRIER (GRAVEL)

Above the Radon Barrier layer, a 6 inch thick Infiltration and Biointrusion Layer of gravel will be placed to provide a barrier to burrowing animals, and a pathway for drainage of water that has infiltrated through upper layers of the cap. The gravel will be a sandy gravel with a gradation in accordance with project plans and specifications. Rock shall be spread to the thickness indicated on the drawings or in accordance with oversizing due to scoring criteria. Rock placement shall be guided by the Computer Aided Earthmoving System to ensure that the appropriate thickness has been placed at all locations. Stone with a D50 of 2 inches or less shall be compacted with a vibratory steel drum.

6.8.1 Biointrusion Layer Materials Testing

Rock for the infiltration and biointrusion barrier layer shall be tested by a commercial testing laboratory during production in accordance with the following:

Biointrusion Layer Material	Reference
Specific Gravity (SSD)	ASTM C-127
Absorption	ASTM C-127
Sodium Sulfate Soundness (5 cycles)	ASTM C-88 (course aggregate)
L.A. Abrasion (100 cycles)	ASTM C-131
Schmidt Rebound Hardness	ISRM Method

Test samples shall be submitted to a commercial testing lab for analysis and subsequent acceptance or rejection or the material represented by the test results, based on engineering calculations.

Rock for the infiltration and biointrusion barrier layer shall be tested for gradation in accordance with ASTMs C-117 and C-136, and other approved testing methods. Test results shall be in accordance with the Design Specification.

Rock for the infiltration and biointrusion barrier layer shall be tested a minimum of four times. The materials shall be tested initially prior to the delivery of any of the materials to the site and at the beginning of placement. Thereafter, the tests shall be performed at a minimum frequency of one test for each 10,000 cubic yards or fractions thereof produced/placed (durability tests for materials produced/gradation tests for materials placed). A final set of durability tests shall be performed near completion of production for each type material. A final gradation test shall be performed near completion of placement for each type material.

Rock for the infiltration and biointrusion barrier layer shall be material that has long-term chemical and physical durability. The material shall achieve an acceptable score for its intended use, in accordance with the rock scoring and acceptance criteria.

6.8.2 Rock Acceptance Criteria

An acceptable rock score depends on the intended use of the rock. The rock's score must meet the following criteria:

- For occasionally saturated areas, which include the top and sides of the final cover, the rock must score at least 50% or the rock is rejected. If the rock scores between 50%

and 80% the rock may be used, but a larger D50 must be provided (oversizing). If the rock score is 80% or greater, no oversizing is required.

- For frequently saturated areas, which include all channels and buried slope toes, the rock must score 65% or the rock is rejected. If the rock scores between 65% and 80%, the rock may be used, but must be oversized. If the rock score is 80% or greater, no oversizing is required.

Oversize rock as follows:

- Subtract the rock score from 80% to determine the amount of oversizing required. For example, a rock with a rating of 70% will require oversizing of 10 percent (80% - 70% = 10%).
- The D50 of the stone shall be increased by the oversizing percent. For example, a stone with a 10% oversizing factor and a D50 of 12 inches will increase to a D50 of 13.2 inches.
- The final thickness of the stone layer shall increase proportionately to the increased D50 rock size. For example, a layer thickness equals twice the D50, such as when the plans call for 24 inches of stone with a D50 of 12 inches, if the stone D50 increases to 13.2, the thickness of the layer of stone with a D50 of 13.2 should be increased to 26.4 inches.

QC Inspector shall verify that the Infiltration and Biointrusion Layer is installed in accordance with Plans and Specifications by checking and confirming:

- Gravel material gradation matches the gradation required in the specifications.
- Gravel material is placed and compacted to produce a continuous uniform thickness of at least 6 inches. As a minimum depth verification will be performed every 10,000 cu yds.
- Compaction is performed by a vibratory steel drum roller, and that the roller makes a minimum of 2 passes over the placed gravel fill.

6.9 FROST PROTECTION LAYER

Above the Infiltration and Biointrusion Layer a 3 feet thick Frost Protection Layer will be installed. This soil layer will provide protection for the low-permeability Radon Barrier Layer beneath. The Frost Protection Layer will consist of 3 ft of clean, compacted soil shall be placed directly on the gravel Infiltration and Biointrusion Layer.

6.9.1 Material

The Frost Protection Layer will be constructed of common fill. The fill shall be produced from stockpiled excavated common fill from the cell excavation, tested to determine its maximum dry density, and the moisture content modified to bring the fill to optimum for compaction in accordance with ASTM D 698.

6.9.2 Ground Preparation

The Frost Protection Layer will be placed directly on the gravel Infiltration and Biointrusion Layer.

6.9.3 Lift Placement and Thickness

The Frost Protection Layer shall be constructed of fill materials placed in continuous lifts of uniform thickness. The method of dumping and spreading of the frost protection layer shall result in loose lifts not to exceed 12”. Scarification shall be performed on all areas of the upper surface of each underlying soil layer prior to placement of the next lift. Scarification shall be accomplished with approved equipment. The final lift of soil shall not be scarified. The final lift shall be smooth rolled with at least 3 passes of the approved smooth steel wheeled roller weighing a minimum of 20,000 pounds.

6.9.4 Inspection and Testing

The Quality Control (QC) Inspector shall visually inspect the material preparation, ground preparation, and fill placement operations. The QC Inspector shall perform in-place density tests with companion moisture tests (optimum moisture plus or minus 5%) to verify that the CAES compaction results in a density of at least 90% of the material’s maximum dry density according to ASTM D698 Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort. The QC Inspector shall verify that the frost protection layer is constructed in accordance with Plans and Specifications by checking and confirming:

- Frost Protection Layer soil is common fill;
- Tests have been performed on the common fill to determine its maximum dry density and optimum moisture content per ASTM D 698.
- Fill material is properly moisture conditioned to near optimum moisture;
- Fill material is placed in continuous and approximately horizontal lifts. The method of dumping and spreading the frost protection layer shall result in loose lifts of nearly uniform thickness, not to exceed 12”.
- Compaction is properly performed.
- Compaction – Fill shall be compacted with a minimum 45,000 lb static weight compactor. The compactor shall be a footed roller capable of kneading compaction, with feet a minimum of 6 inches in length. The compactor shall be equipped with a Computer Aided Earthmoving System and soil placement and compaction shall be controlled by the CAES.

- Compaction by CAES – the QC inspector shall monitor CAES compaction by visually inspecting the process and reviewing the computer records for each layer of soil placed.
- Compaction Verification Tests – Perform in-place density and moisture content tests on compacted fill material in accordance with the following requirements:
  - Verification tests of in-place density shall be performed on initial layers of soil placed, and on any layers in which the CAES indicates that problems occurred obtaining compaction.
  - When verification in-place density and moisture content tests are performed on a soil layer, a minimum of one test shall be preformed a minimum of 2 tests per 5,000 cubic yards of fill material placed.
  - Compaction and moisture content tests shall be performed in accordance with the following methods:
    - ASTM D 1556 – Density and Unit Weight of Soil in Place by the Sand-Cone Method
    - ASTM D 2216 – Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
    - ASTM D 2922 - Density of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth)
    - ASTM D 6938 - In-Place Density and Water content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)
    - ASTM D 4643 - Determination of Water (Moisture) Content of Soil by the Microwave Oven Heating

    Note: Companion sand cone tests and oven moisture tests must be performed along with nuclear tests until a sufficient number have been performed to demonstrate a clear correlation.

6.9.5 Initial and Confirmatory Surveys

Verification of the thickness of the Frost Protection Layer will be performed by comparing before and after surveys of the Layer. Prior to placement of the Frost protection Layer, an initial survey shall be performed of the section to be capped. The initial survey will document the geometry of the top of the Infiltration and Biointrusion Layer. After the Frost Protection Layer has been installed, a post-installation survey will be performed on the top of the Frost Protection Layer to confirm that the total fill thickness is in accordance with the plans and specifications.

6.10 ROCK ARMORING

The final cap layer is Rock Armoring, placed over the Frost Protection Layer. The Rock Armoring will vary in size and thickness at different locations on the cap, and shall be installed in accordance with the project plans and specifications Rock shall be spread to the thickness indicated on the drawings or in accordance with oversizing due to scoring criteria. Rock placement shall be guided by the Computer Aided Earthmoving System to ensure that the appropriate thickness has been placed at all locations. Stone with a D50 of 2 inches or less shall be compacted with a vibratory steel drum.

6.10.1 Erosion Protection Materials Testing

Rock for the final cover layers shall be tested by a commercial testing laboratory during production in accordance with the following:

Rock Armoring	Reference
Specific Gravity (SSD)	ASTM C-127
Absorption	ASTM C-127
Sodium Sulfate Soundness (5 cycles)	ASTM C-88 (course aggregate)
L.A. Abrasion (100 cycles)	ASTM C-131
Schmidt Rebound Hardness	ISRM Method

Test samples shall be submitted to a commercial testing lab for analysis and subsequent acceptance or rejection or the material represented by the test results, based on engineering calculations.

Rock for the final cover layers shall be tested for gradation in accordance with ASTMs C-117 and C-136, and other approved testing methods. Test results shall be in accordance with the Design Specification.

Rock for the final cover layers shall be tested a minimum of four times. The materials shall be tested initially prior to the delivery of any of the materials to the site and at the beginning of placement. Thereafter, the tests shall be performed prior to placement at a minimum frequency of one test for each 10,000 cubic yards or fractions thereof produced/placed (durability tests for materials produced/gradation tests for materials placed). Where the total volume is less than 30,000 cubic yards, the test frequency shall be one test for each type material when approximately one-third and two thirds of the total volume of material has been produced/placed. A final set of durability tests shall be performed near completion of production for each type material. A final gradation test shall be performed near completion of placement for each type material.

Rock for the final cover layers shall be rock material that has long-term chemical and physical durability. Rock for final cover layers shall achieve an acceptable score for its intended use, in accordance with the rock scoring and acceptance criteria.

At the quarry operations periodically a geologist will inspect the stockpiles to ensure the percent of other than grey basalt does not exceed 10% for rock for the final cover layers.

6.10.2 Rock Acceptance Criteria

An acceptable rock score depends on the intended use of the rock. The rock's score must meet the following criteria:

- For occasionally saturated areas, which include the top and sides of the final cover, the rock must score at least 50% or the rock is rejected. If the rock scores between 50% and 80% the rock may be used, but a larger D50 must be provided (oversizing). If the rock score is 80% or greater, no oversizing is required.
- For frequently saturated areas, which include all channels and buried slope toes, the rock must score 65% or the rock is rejected. If the rock scores between 65% and 80%, the rock may be used, but must be oversized. If the rock score is 80% or greater, no oversizing is required.

Oversize rock as follows:

- Subtract the rock score from 80% to determine the amount of oversizing required. For example, a rock with a rating of 70% will require oversizing of 10 percent (80% - 70% = 10%).
- The D50 of the stone shall be increased by the oversizing percent. For example, a stone with a 10% oversizing factor and a D50 of 12 inches will increase to a D50 of 13.2 inches.
- The final thickness of the stone layer shall increase proportionately to the increased D50 rock size. For example, a layer thickness equals twice the D50, such as when the plans call for 24 inches of stone with a D50 of 12 inches, if the stone D50 increases to 13.2, the thickness of the layer of stone with a D50 of 13.2 should be increased to 26.4 inches.

QC Inspector shall verify that the Rock Armoring is installed in accordance with Plans and Specifications by checking and confirming:

- Stone gradations match the gradation required in the specifications and based on visual verification, fines (material < 200 mesh) are dispersed evenly throughout the rock.
- Stone material is placed to produce the thickness required by the plans for each area. As a minimum, depth verification will be performed every 10,000 cu yds.

Cell Component	Material of Construction	Compaction Requirements	Lift Thickness max./ approx loose / compact	Frequency of Verification Tests
Cell Excavation	N/A	N/A	N/A	N/A
Perimeter Embankment	Common Fill	95%	12” / 10”	Initial layer / Section 6.3.4
RRM Placement	RRM	90%	12” / 10”	Initial layer / Section 6.4.3
Interim Cover	Common Fill	90%	12 / 10”	Initial layer / Section 6.5.4
Radon Barrier	Mancos Shale	95%	12” / 10”	Initial layer / Section 6.7.4
Infiltration and Bio-intrusion Barrier	Stone	N/A	N/A	N/A
Frost Protection	Common Fill	90%	12” / 10”	Initial layer / Section 6.9.4
Cap Armoring	Stone	N/A	N/A	N/A

Cell Construction Material Installation Summary Table

6.11 SETTLEMENT MONITORING

A grid system shall be established for periodic surveys to monitor cell settlement. This system will be transferred to Legacy Management (LM) for continued cell settlement monitoring.

7.0 RECORDS

7.1 Test and inspection records shall be reported and filed in a timely manner, consistent with the status of work performed. Inspection and test status shall be available at all times to prevent inadvertent by-passing of an inspection or test.

7.2 Test and inspection records shall contain, at a minimum, the following:

7.2.1 Items tested or inspected.

7.2.2 Date of test or inspection.

7.2.3 Tester/inspector.

7.2.4 Type of test or inspection.

7.2.5 Results and acceptability, including the test or inspection acceptance criteria.

7.2.6 Identification number of instrument used in performing the test or inspection.

7.2.7 Action taken in connection with any deviations noted.

7.2.8 Person evaluating test results, if different from person named in paragraph

7.3 Test and inspection records shall be filed and maintained in accordance with DOE-EM/GJT1545 “Records Management Manual.”

7.4 Surveillances shall be performed by Quality Assurance of M&TE used by Quality Control.

7.5 Daily Inspection Reports shall be generated, describing the adequacy, discrepancies, progress, dispositions and details of each day’s construction activities.

7.6 Permanent QA/QC records shall be periodically evaluated through internal and external surveillances and audits.

7.7 A weekly Quality Control Report shall be generated, summarizing the volume of in-placed materials and the number of field and laboratory tests performed for each type of material. A copy of the weekly QC Report shall be transmitted to the ES Quality Manager.

ADDENDUM E

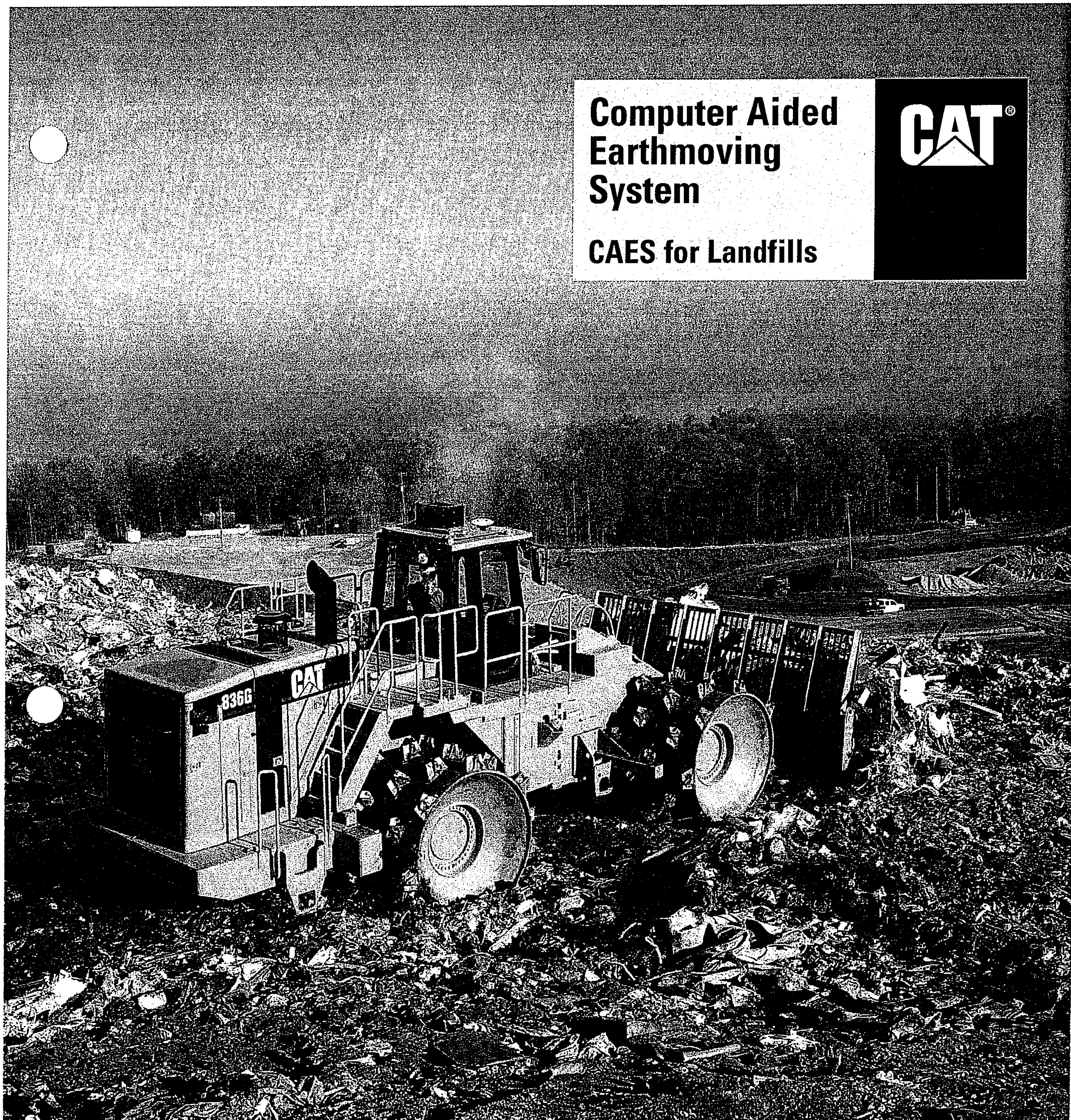
Attachment 1

Computer Aided Earthmoving System

(To Print, right click on the following CAES Document and select "Acrobat Document Object" then "open" to see the entire CAES brochure)

Computer Aided Earthmoving System

CAES for Landfills

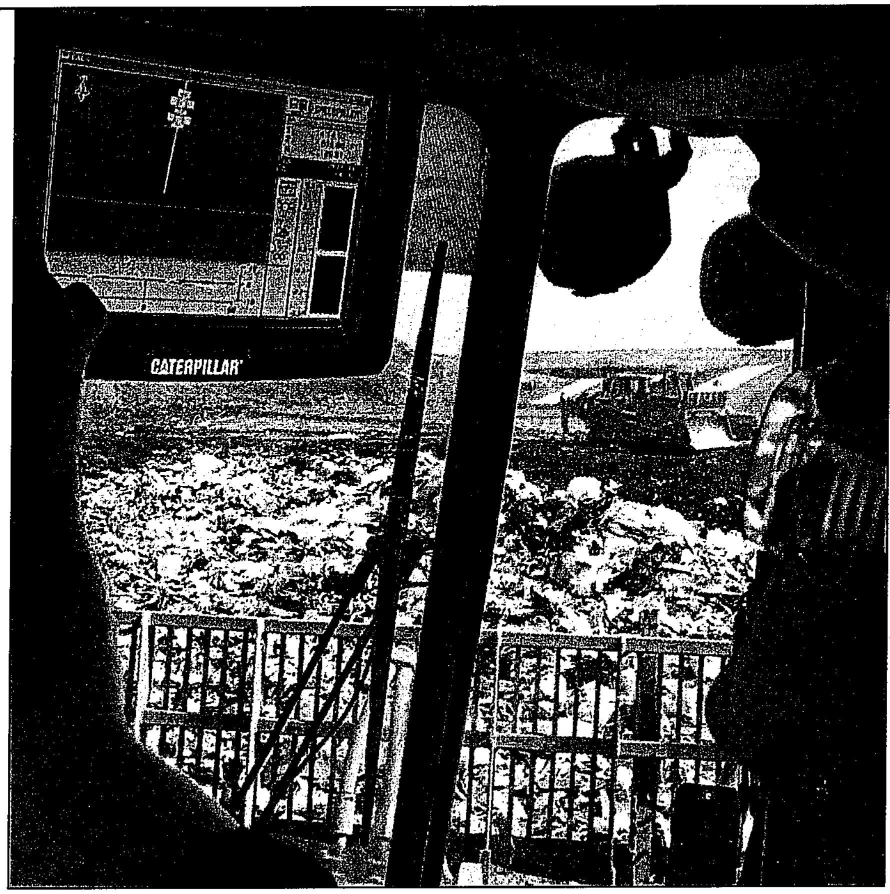


Landfill Compactors
Track-Type Tractors
Wheel Tractor Scrapers
Motor Graders

System Components	
Communications Radio	TC900B
GPS Antenna	L1/L2
GPS Receiver	MS840
In-Cab Display	CAES Touch Screen Display
CAESoffice™/METSmanager	

Computer Aided Earthmoving System for Landfills

Advanced GPS technologies for earthmoving equipment improve machine efficiency, maximize air space utilization, and extend landfill life.



Caterpillar is helping customers revolutionize the way they compact trash, grade slopes and manage their operation with new technology solutions for landfills. Solutions that provide greater accuracy, higher productivity, lower operating costs, more profitability and longer landfill life.

The Computer Aided Earthmoving System (CAES) is a high technology earthmoving tool that allows machine operators to achieve maximum landfill compaction, desired grade/slope, and conserve and ensure even distribution of valuable cover soil with increased accuracy without the use of traditional survey stakes and crews. Using global positioning system (GPS) technology, machine-mounted components, a radio network, and office management software, this state-of-the-art machine control system delivers real-time elevation, compaction and grade control information to machine operators on an in-cab display. By monitoring grade and compaction progress, operators have the information they need to maximize the efficiency of the machine, resulting in proper drainage and optimum airspace utilization.

This advanced technology tool also aids in the identification of site-specific storage areas for hazardous, medical, industrial, and organic waste requiring special handling and placement records.

Applications

CAES is an ideal tool for landfill planning, engineering, surveying, grade control, and production monitoring applications in dump areas. CAES is specifically designed for use on landfill compactors, track-type tractors, wheel tractor scrapers, and motor graders.

On-Board Components

- CAES Touch Screen Display
- GPS Receiver
- GPS Antenna (L1/L2)
- Communications Radio

Off-Board Components

- GPS Reference Station
- Radio Network
- CAESoffice/METSmanager

Operation

CAES uses GPS technology, a wireless radio communications network, and office software to map landfills, create site plans, locate a machine's position, and track compaction and earthmoving progress with complete accuracy.

The receiver uses signals from GPS satellites to determine precise machine positioning. Two receivers are used to capture and collect satellite data – one located at a stationary spot on the landfill site, and another located on the machine. Signals from the ground-based reference station and on-board computer are used to remove errors in satellite measurements for centimeter accuracy.

The CAES-enabled machine is driven over the site to create a digital terrain design file. Using the radio network and office software, landfill terrain data is transmitted from the machine to the landfill office. Landfill managers can then send the work plan from the office to the in-cab display to show operators the work to be done.

The in-cab display provides the operator with an overhead and cross-sectional three-dimensional surface view of the color-coded work plan and precise machine location. The software continuously updates terrain and machine position information as the machine traverses the site.

CAES gives the operator the ability to control grade by monitoring progress on the in-cab display, which shows a graphical representation of lift thickness and compaction density. Cut/fill numbers are displayed in real-time as the machine moves across the site, which allows the operator to know precise elevation, material spread, compaction passes, and required cut or fill at any point on the job.

The *compactor* display shows colored grids representing the number of compaction passes the machine has made across each area. As the compactor wheel travels over an area, the screen changes color to acknowledge the pass. Green areas indicate when optimum compaction has been reached. The system also monitors thick lift information and visually displays when a lift exceeds maximum site parameters.

In *tractor, scraper and motor grader* applications, the color display graphically shows the operator cut, fill, and grade work to be done according to plan. As the machine works, the screen changes color. Green indicates when the operator has achieved plan grade.

By providing immediate feedback on the accuracy of each pass, CAES operators have the information and confidence they need to work more efficiently, productively and profitably.

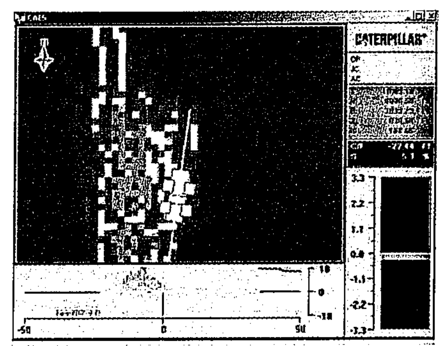
On-Board Components

Communications Radio. The rugged radio, mounted on the roof of the machine, is used for transmitting, repeating and receiving real-time data from GPS receivers. The radio broadcasts real-time, high-precision data for GPS applications. Under normal conditions, the 900 MHz radio broadcasts data up to 10 km (6.2 miles) line-of-sight. Coverage can be enhanced with a network of repeaters, which allows coverage over a broader area. Optimized for GPS with increased sensitivity and jamming immunity, the radio features error correction and high-speed data transfer, ensuring optimum performance. A 450 MHz radio solution is also available.

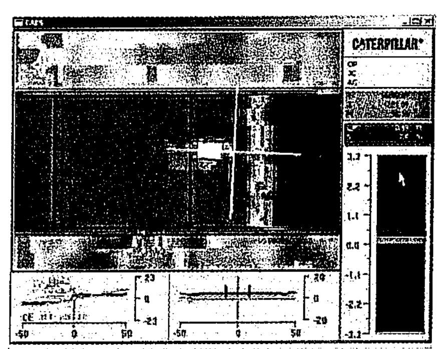
GPS Antenna (L1/L2). The dual frequency external antenna, mounted on the roof of the machine and reference station, is used to pick up the signals from the GPS satellites to determine the machine's position for high precision, real-time machine guidance and control. A low-noise amplifier provides sensitive performance in demanding applications. The compact, low profile design and sealed housing ensure reliable performance in harsh weather conditions.

GPS Receiver. The dual frequency real-time kinematic (RTK) GPS receiver is used to send and receive data simultaneously across the radio network. The system computes differential corrections for real-time positioning with centimeter accuracies, to ensure precise machine guidance and control.

CAES Touch Screen Display. The in-cab graphical display provides real-time operating information to the operator. Designed for simple operation, the 264 mm (10.4 in) custom configurable, integrated touch screen display allows operators to easily interface with the CAES system. The display utilizes the latest infrared touch and transflective backlight technology for superior viewing in bright light conditions and a broad-range dimmable backlight for viewing in low light conditions. Designed for reliable performance in extreme operating conditions, the unit is guarded against shock and sealed to keep out dust and moisture.

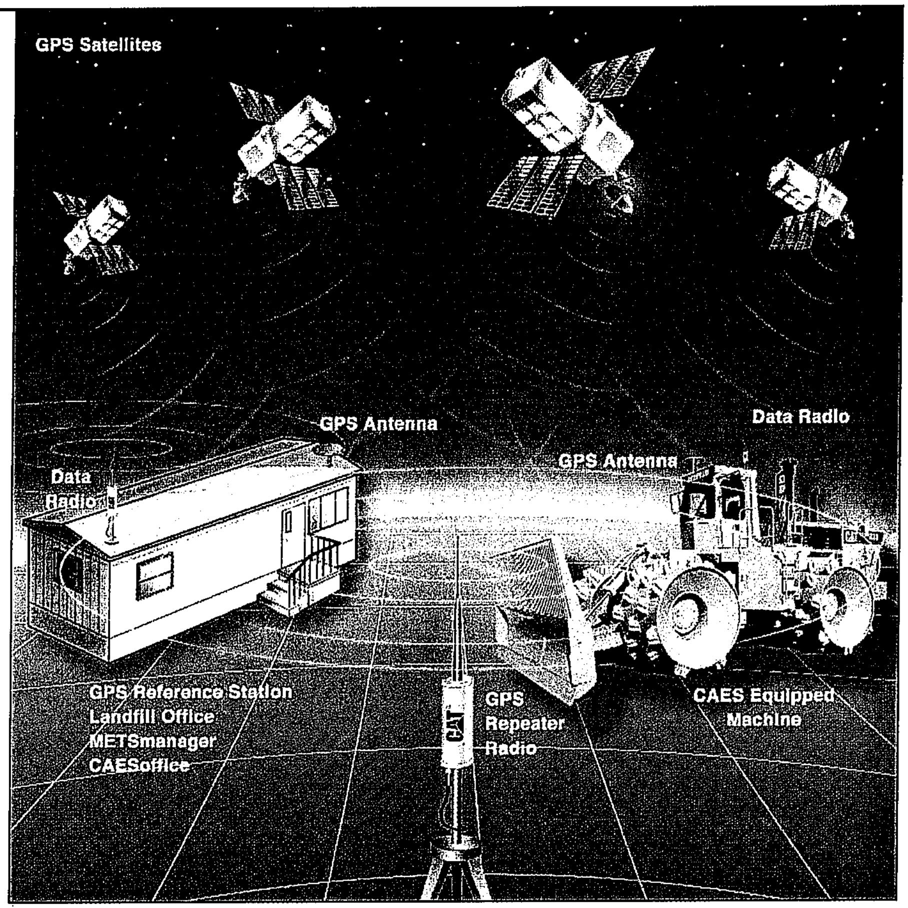


Compactor Screen



Dozer Screen

Off-Board Components



GPS Technology. Global Positioning System (GPS) technology uses 24+ satellites that orbit above the earth and constantly transmit their positions, identities and times of signal broadcasts to earth-based satellite sensors. The GPS receiver is an electronic box, which measures the distance to each visible satellite from an antenna on the ground. Through trilateralization, the receiver determines where the satellite is in respect to the center of the earth. The GPS receiver uses its own position and GPS satellite positions to calculate errors and corrections for computing exact location and precise positioning with centimeter accuracy.

GPS Reference Station. A GPS reference station is used to achieve the centimeter level accuracy needed in a landfill application. The reference station sends GPS information over a radio link to the GPS receiver on the CAES-enabled machine. The receiver combines the information with its own observations to compute precise positioning.

Radio Network. The radio network for CAES has two channels. GPS correction data is transmitted over one channel, while the other channel is used to send site planning and production data to the machine and from the machine back to the site office. By utilizing the same radio as a repeater the range can be extended to provide seamless coverage around local obstacles such as hills or large buildings. Up to four radio repeaters may be used to provide extended coverage.

Landfill Planning Software. Site planning and surveying begins with the landfill planning software. CAES is compatible with most third party CAD planning software packages. Data formats used between the CAES software and the planning software are industry standard .DXF and ASCII.

CAESoffice™. The powerful Caterpillar-designed CAESoffice software enables landfill management to monitor CAES-equipped machines and work progress throughout the site in near real-time. The data is stored in a database format for easy customized access, reporting and editing.

METSmanager. This software package allows for integration of the landfill planning system and the machine. It provides the user interface for CAES and controls all communications over the wireless radio network. METSmanager reads design files in standard .DXF formats, converts them to CAES format (.CAT), and sends the design files to the on-board display on the machine over the radio network. This program continually updates the site model by regularly requesting data transmissions from the machine to the office.

- **File Window.** Displays design files (.DXF) created using the site planning package, and holds application configuration files for GPS receivers and files converted from .DXF to the CAES on-board software format (.CAT).
- **Machines Window.** Shows icons of each machine equipped with CAES on-board software. Allows multiple machines to be monitored at the same time.
- **Messages Window.** Contains a list of recent error, warning, confirmation, or information messages generated by METSmanager.
- **Communications Queue Window.** Lists all file transmissions scheduled to occur over the radio network and displays transmission status for all files.

Specifications

TC900B Communications Radio

- Technology: Spread spectrum
- Modes: Base, repeater, rover
- Optimal Range: 10 km (6 miles), line-of-sight
- Typical Range: 3-5 km (2-3 miles) varies w/terrain and operating conditions. Repeaters may be used to extend range
- Frequency Range: 902-928 MHz
- Networks: Ten, user selectable
- Transmit Power: Meets FCC requirements, 1 watt max.
- License Free (U.S. and Canada)
- Wireless Data Rates: 128 Kbps[2]
- Operating Temperature: –40° C to 70° C (–40° F to 158° F)
- Storage Temperature: –40° C to 85° C (–40° F to 185° F)
- Humidity: 100%
- Sealing: Exceeds MIL-STD-810E, sealed to ±34.5 kPa (±5 psi), immersible to 1 m (39 in)
- Vibration: 8 gRMS, 20-2000 Hz
- Operational Shock: ±40 g, 10 msec
- Survival Shock: ±75 g, 6 msec
- Electrical Input: 10.5 to 20V DC
- Nominal Current: 250 mA (3 W)1
- Transmit Current: 1000 mA (12 W)1
- Protection: Reverse polarity
- Control Interface: SAE J1939 CAN
- Emissions and Susceptibility: CE compliant, exceeds ISO 13766
- Input Connector: 8-pin
- Network Connector: 8-pin
- Height: 250 mm (10 in)
- Width: 85 mm (3.4 in)
- Weight: 0.9 kg (2.0 lb)

Radios outside of U.S. and Canada operate on different frequencies. Please contact your Cat Dealer for specifics.

L1/L2 GPS Antenna

- Operating Temperature: –40° C to 70° C (–40° F to 158° F)
- Storage Temperature: –55° C to 85° C (–67° F to 185° F)
- Height: 151mm (6 in)
- Width: 330 mm (13 in)
- Depth: 72 mm (2.8 in)
- Weight: 1.695 kg (3.8 lb)

MS840 GPS Receiver

- Tracking: 9 channels L1 C/A code, L1/L2 full cycle carrier, fully operational during P-code encryption
- Signal Processing: Supertrak multibit technology, Everest multipath suppression
- Positioning Mode –
- Synchronized RTK: 1 cm + 2 ppm horizontal accuracy/2 cm + 2 ppm vertical accuracy, 300 ms latency, 5 Hz std. maximum rate
- Low Latency: 2 cm + 2 ppm horizontal accuracy/3 cm + 2 ppm vertical accuracy, <20 ms latency, 20 Hz maximum rate
- DPGS: <1m accuracy, <20 ms latency, 20 Hz maximum rate
- Range: Up to 20 km from base for RTK
- Communication: 3x RS-232 ports, baud rates up to 115,200
- Control Interface: SAE J1939 CAN
- Configuration: RS-232 Serial connection
- Operating Temperature: –20° C to 60° C (–4° F to 140° F)
- Storage Temperature: –30° C to 80° C (–22° F to 176° F)
- Humidity: 100%
- Operational Vibration: 3 gRMS
- Survival Vibration: 6.2 gRMS
- Operational Shock: ±40 g
- Survival Shock: ±75 g
- Electrical Input: 12/24V DC, 9 watts
- Height: 5.1 cm (2.0 in)
- Width: 14.5 cm (5.7 in)
- Depth: 23.9 cm (9.4 in)
- Weight: 1.0 kg (2.25 lb)

CAES Touch Screen Display

- LCD Display: 264 mm (10.4 in) 640 × 480 transflective color VGA
- Buttons: touch screen
- Touch Screen: 3.17 mm (0.125 in) resolution infrared high light rejection
- Back Light: 200 cd/m2, 200:1 dimming ratio
- Processor: Intel Pentium CPU
- Memory: 64 MB Ram
- Solid State Disk: Internal 128 MB, external compact flash
- Operating Environment: Embedded WinNT
- Operating Temperature: –20° C to 70° C (–4° F to 158° F)
- Storage Temperature: –50° C to 85° C (–58° F to 185° F)
- Sealing: IP68 sealed to ±5 psi
- Humidity: 100%
- Electrical Input: 9-32V DC
- Power Supply: 5 amp @ 40W load dump, reverse voltage, ESD, over voltage protection
- Connector: 70-pin
- Discrete I/O: 8 digital ports; 5 PMW inputs
- Mounting: bracket or panel
- Height: 261 mm (10.28 in)
- Width: 315 mm (12.4 in)
- Depth: 93 mm (3.66 in)
- Weight: 3.17 kg (8.5 lb)

CAESoffice/METSmanager PC Requirements

- Pentium II/III processor w/ 128 MB memory
- 21 in. monitor (SVGA color 1024 × 768 resolution) with 2MB video memory
- Windows NT 4.0 or higher with latest service pack
- Modem- internal or external (required for remote support)
- Required ports: serial (suggest 2 serial, 1 parallel)
- CD ROM drive
- 3.5 in disk drive
- Mouse or suitable pointing device
- Hard Drive Space: 200 MB min.

Customer Support. For over 25 years, Caterpillar has been providing electronic and electrical components and systems for the earthmoving industry – real world technology solutions that enhance the value of Cat products and make customers more productive and profitable. Your Cat Dealer is ready to assist you with matching machine systems to the application or obtaining responsible, knowledgeable support. For additional information, please contact us at LANDFILLGPS@CAT.com

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