DRAFT 03

Geophysical Verification and Monitoring Work Plan for In Situ Vitrification (ISV) Cold Demonstration at Los Alamos National Laboratory (LANL) Draft 03

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February 26, 1999

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1. INTRODUCTION

MSE-Technology Applications (MSE) is funded by the Subsurface Containment Focus Area (SCFA) and the U.S. Department of Energy (DOE) under TTP#FT18SS21 to coordinate and facilitate a demonstration of Non-Traditional In-Situ Vitrification (NTISV) technology. This demonstration intends to supply data suitable to support a CERCLA Treatability Study designed to illustrate the feasibility and applicability of NTISV technology to immobilize buried radioactive and hazardous waste.

The in situ vitrification (ISV) demonstration will be a two phase project. The first phase will be a cold demonstration and if successful, a hot demonstration will follow. As part of MSE's task to demonstrate the use of in situ vitrification for waste stabilization, a method of verifying the vitrified waste's integrity must be developed and demonstrated.

1.1. Purpose

The purpose of the work outlined in this plan is to develop and demonstrate the ability to construct tomographic images of the vitrified mass to verify that complete vitrification has taken place. The tomographic images will indicate the size, shape and extent of the vitrified mass. In addition, these methods may be used to monitor the progress of the vitrification process.

1.2. Scope of Work

The primary objectives for the first phase (Cold Demonstration) of the ISV demonstration include:

- Determine the most effective method(s) of verifying that complete vitrification has taken place;
- Design a system for verifying that complete vitrification has taken place;
- Implement the system design for verifying that complete vitrification has taken place; and
- Construct tomographic images of the vitrified mass showing the size, shape and extent of the vitrified mass.

The primary objectives for the second phase (Hot Demonstration) of the ISV demonstration include:

- Based on lessons learned from the cold demonstration, design a system for verifying that complete

vitrification has taken place for the hot demonstration;

- Implement the system design for verifying that complete vitrification has taken place for the hot demonstration; and
- Construct tomographic images of the vitrified mass showing the size, shape and extent of the vitrified mass.

1.3. Geophysical Methods Investigated

Methods of tomography that will be investigated for the purpose of imaging the vitrified mass for the Cold Demonstration include:

- Seismic Tomography;
- Ground Penetrating Radar (GPR) Tomography; and
- Electrical Resistance Tomography (ERT).

Tomography is the process of forming images of the interior of an object from measurements made outside of the object along rays passed through the object (Menke, 1989). For this process, the measurements will be made from boreholes installed outside of the melt area and from the ground surface.

1.3.1. Seismic Velocity Tomography

Field methods for acquiring seismic tomography data typically entail placing a series of seismic receivers (in this case, hydrophones) into a borehole and a seismic source in an adjacent borehole or at the ground surface and recording the travel time for the seismic energy from source to receiver locations. The source is moved to a new location and the process repeated until a sufficient number of travel times have been recorded along ray paths through the area of interest.

The travel time data are inverted to estimate a velocity distribution of the interior of the area of interest. The velocity distribution is related to the material property distribution (primarily density) within the area of interest and thus provides an image of the interior of the area of interest. For this project, the tomographic inversion of the travel time data will be completed using GEOTOMAN, a three dimensional tomographic data inversion package

originally developed by the U.S. Bureau of Mines under the name 3DTOM.

GEOTOMAN can also be used for forward modeling studies to design the borehole placement and source and receiver geometry. This is an important to ensure useful data are being collected and to avoid misplacing the boreholes.

1.3.2. Ground Penetrating Radar (GPR) Tomography

GPR tomography data are taken in a similar manner to seismic tomography data. Several travel time measurements are made outside of the area of interest along ray paths through the area of interest. The measurements can be made from adjacent boreholes or from the ground surface to a borehole.

The GPR travel time data will also be inverted using the GEOTOMAN software and an estimate of the GPR velocity will be obtained. This velocity distribution is also a function of the materials properties within the area of interest, however, rather than density, it is more closely related to electrical properties.

1.3.3. Electrical Resistance Tomography (ERT)

Electrical resistivity is a fundamental property of rock materials and is closely related to the rock type. The determination of the subsurface distribution of resistivity from measurements on the ground surface or from boreholes can yield useful information on the structure or composition of the subsurface. The most common method of making these types of measurements involves the passage into the earth of direct (or very low frequency) current and measuring the electrical potential between different locations using a pair of receiver, or potential, electrodes. The electrical resistivity is then determined from the magnitude of the current and voltage and the geometric factor for the electrode configuration.

Electrical resistivity methods can be used in a cross-structure tomographic mode, commonly called electrical resistance tomography (ERT), in which the measurements are made from both current and potential electrodes located in the subsurface. The electrodes can be installed in boreholes or using a push type of technology.

The ERT data are inverted to estimate a 2D planar distribution of electrical resistance between a pair of boreholes

(this is the traditional tomographic format) or the data can be inverted to estimate a 3D volumetric distribution of the electrical resistance for the area of interest.

1.4 Success Criteria

The success of this project will be based on a comparison of the results of the tomographic imaging to the dimensions of the vitrified mass determined through the excavation of the vitrified mass after it as been allowed to cool sufficiently. The excavation will be carried out by Geosafe as specified in the NTISV Demonstration Plan.

The tomographic imaging will be considered successful if the estimated dimensions of the monolith as determined by the tomographic imaging are within +/- 20% of the estimated dimensions of the monolith as determined during the excavation.

2. SITE PREPARATION

The ISV Cold Demonstration, scheduled for Spring 1999, will be completed at the Los Alamos National Laboratory (LANL) in Los Alamos, New Mexico. If successful, the Hot Demonstration will also take place at LANL.

2.1. Site Location/Description

LANL is located on the Pajarito Plateau, about 35 miles northwest of Santa Fe. The lab covers more than 43 square miles. (See Figure 1.) The site chosen for the Cold Demonstration is located to the north of the MDA-V site, off of the southwest corner of the parking lot. (See Figure 2.)

Geology at the LANL Cold Demonstration site consists of volcanic units. These units include, from top to bottom, the Tshirege Unit (~350 ft thick), the Cerro Toledo Interval (~45 ft thick), the Otowi Member (~270 ft thick), the Guaje Pumice Bed (~25 ft thick), and the Puye Formation. The Tshirege Unit and Otowi Member are primarily nonwelded to partially welded tuff. ISV work for the Cold Demonstration will be completed in the upper portion of the Tshirege Unit.

The ISV process for the Cold Demonstration will be completed by Geosafe Corporation. As part of the site

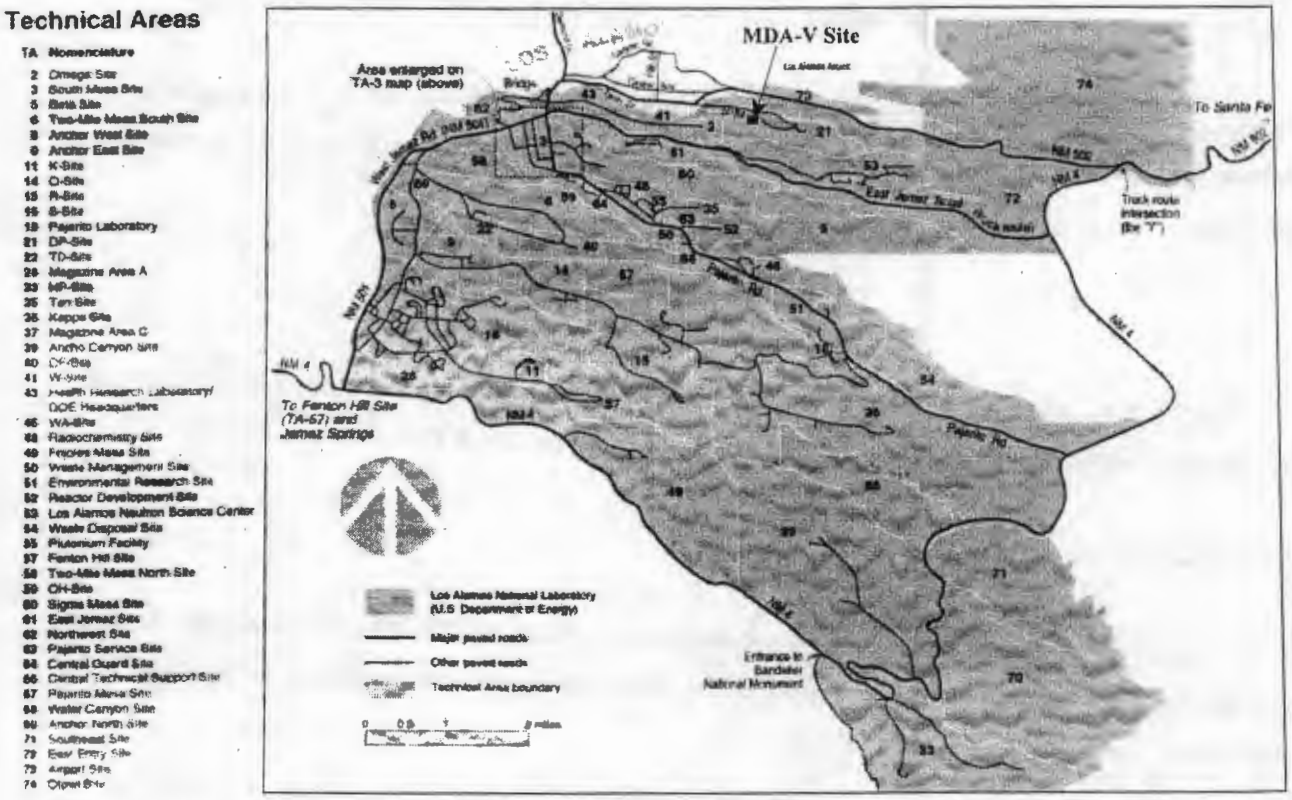


Figure 1. Los Alamos National Laboratory (LANL)

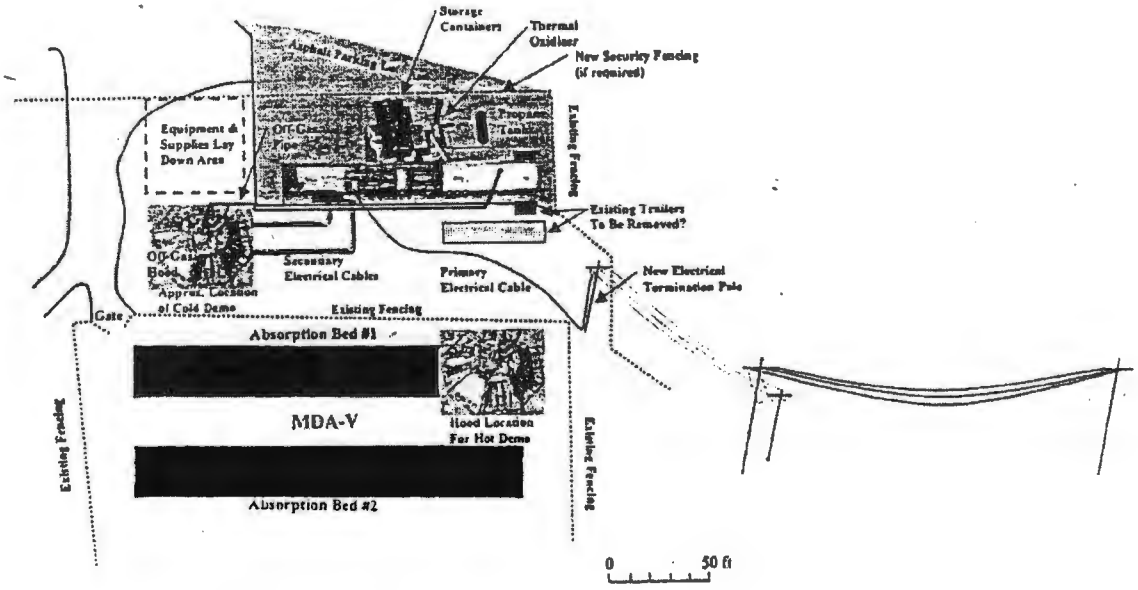


Figure 2. Plan View of MDA-V Site at LANL

preparation Geosafe will have an area approximately 60 feet in diameter leveled to ±6 inches. The center of the area will be located directly over the center position of the Cold Demonstration bed. Geosafe's off-gas collection hood will also be centered on the leveled area.

2.2. Forward Modeling

To determine the geophysical access port configuration for the Cold Demonstration, forward seismic travel time models were used to generate synthetic data that was then inverted to determine the optimal borehole separation and source receiver spacing. ERT forward models will be constructed to determine the relative accuracy of a given electrode configuration and spacing.

2.2.1. Seismic Velocity Tomography Forward Modeling

Seismic travel time forward modeling was completed using the tomography software GEOTOMAN. Originally developed by the Bureau of Mines, GEOTOMAN is used for three-dimensional imaging of the subsurface. Forward modeling using GEOTOMAN is useful for evaluating the resolving power of an experimental geometry (Ref. 1). Result of the seismic forward modeling indicated that a borehole separation of 50 feet and surface to borehole measurements would be sufficient for imaging the vitrified mass.

2.2.2. Electrical Resistance Tomography (ERT) Forward Modeling

Electrical resistance tomography (ERT) forward modeling will be completed assuming a 50 foot borehole separation. ERT forward modeling will be accomplished using OCC2D3D v1.0. OCC2D3D allows the forward

and inverse modeling of electrical resistivity and induced polarization (IP) data. Results from the forward modeling will show the relative accuracy of the electrode configuration and spacing for the ISV Cold Demonstration site.

2.3. Geophysical Access Port Installation

Geophysical verification data acquisition for the ISV Cold Demonstration will require the installation of four geophysical access ports or boreholes. These ports will provide a means for acquiring the necessary seismic, electrical resistance, and GPR data. The access ports will be installed approximately 25 feet from the center

position of the Cold Demonstration bed and offset from each side of the proposed melt area. (See Figure 3.) Once completed, the access ports will be surveyed for x, y, and z locations of the top of the ports and the deviation of the ports will also be measured.

Boreholes will be 4 inches in diameter and installed to a depth of 50 feet below ground surface (bgs) using a method that minimizes or eliminates bringing drill cuttings to the surface. Boreholes will be completed with a flush threaded 2 inch PVC well casing sealed at the bottom with a threaded PVC plug. A series of electrodes will be attached to the outside of the PVC casing and extend from the ground surface to the bottom of the casing.. The electrodes will be used for taking ERT data and will consist of a 3/8 inch diameter multiconductor electrical cable with stainless steel screen electrodes attached every 3 feet along the length of the cable. The casing will extend from the bottom of the borehole to ½ feet bgs and be grouted into the borehole using a cement bentonite grout. Surface completion will consist of a flush mount monitoring well cover set into a cement pad. (See Figure 4.)

3. GEOPHYSICAL BASELINE ASSESSMENT

Prior to performing the ISV Cold Demonstration melt, a set of baseline geophysical data will be acquired including, surface to borehole seismic data, borehole to borehole electrical resistivity data, and borehole to borehole and surface to borehole GPR data. Data acquisition will be completed before the off-gas collection hood is moved over the site.

3.1. Baseline Seismic Velocity Tomography

Surface to borehole seismic data will be acquired to determine the seismic velocity distribution in the subsurface and test trench prior to the ISV melt. Baseline data will make it possible to determine if seismic velocity anomalies are a result of the melt process or an original feature.

3.1.1. Baseline Seismic Velocity Tomography Data Acquisition

Surface to borehole seismic data will be acquired along the two planes between the access port pairs spaced 50 feet apart (See Figure 5.) A seismic source will be positioned between each access port pair at a 5 foot increment. Seismic receivers, spaced 1 foot apart, will be placed in each geophysical access port. The access ports will be

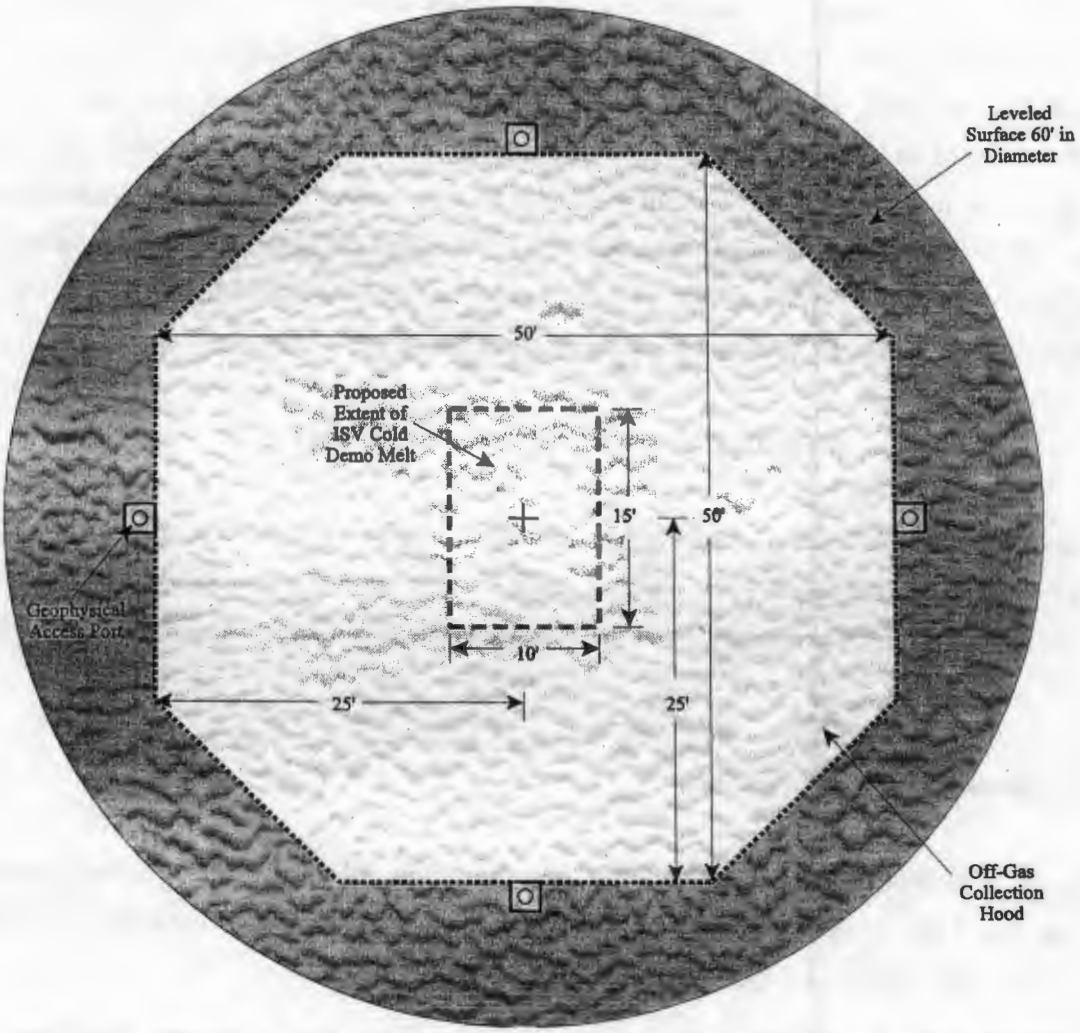


Figure 3. Plan View of Cold Demonstration Site Showing Geophysical Access Port Locations

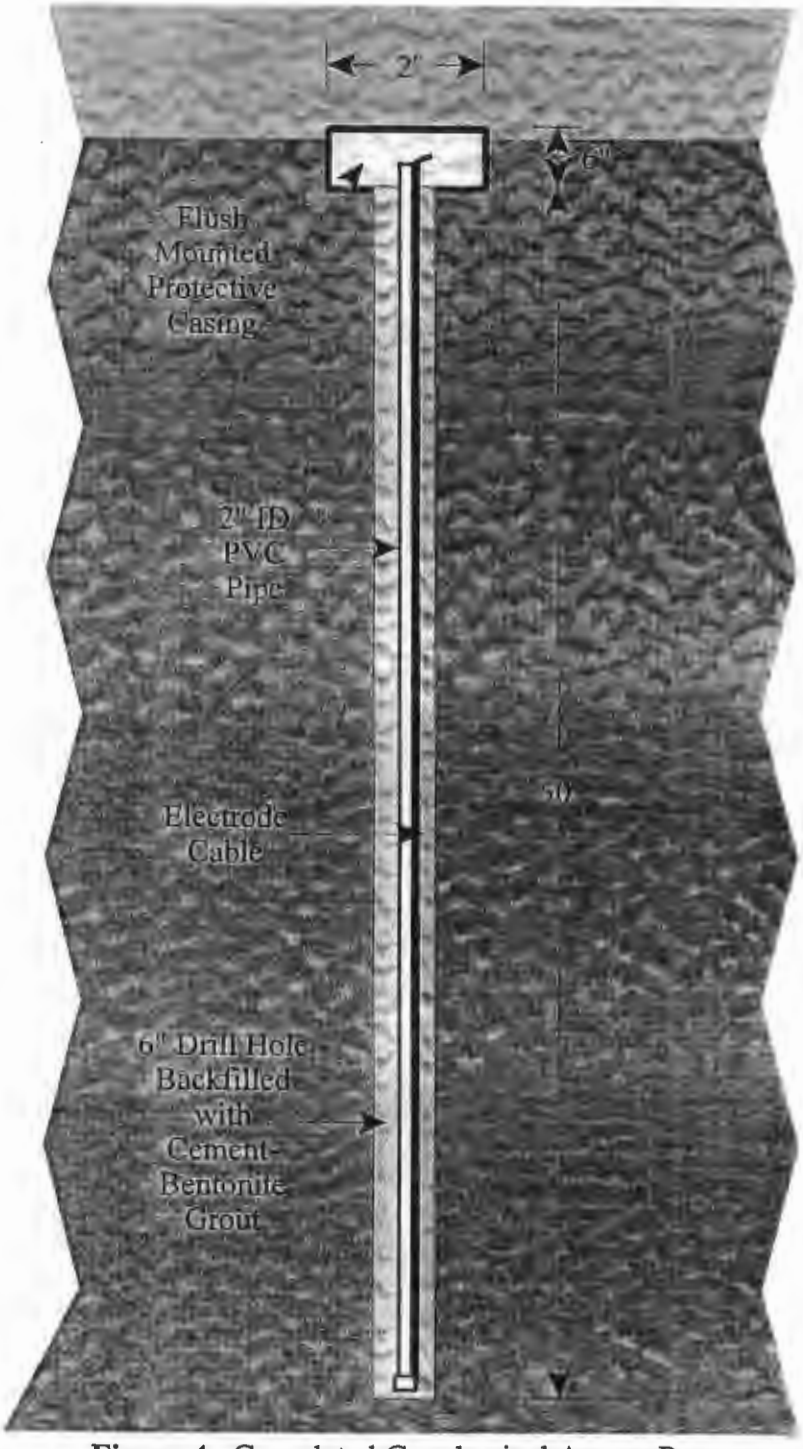


Figure 4. Completed Geophysical Access Port

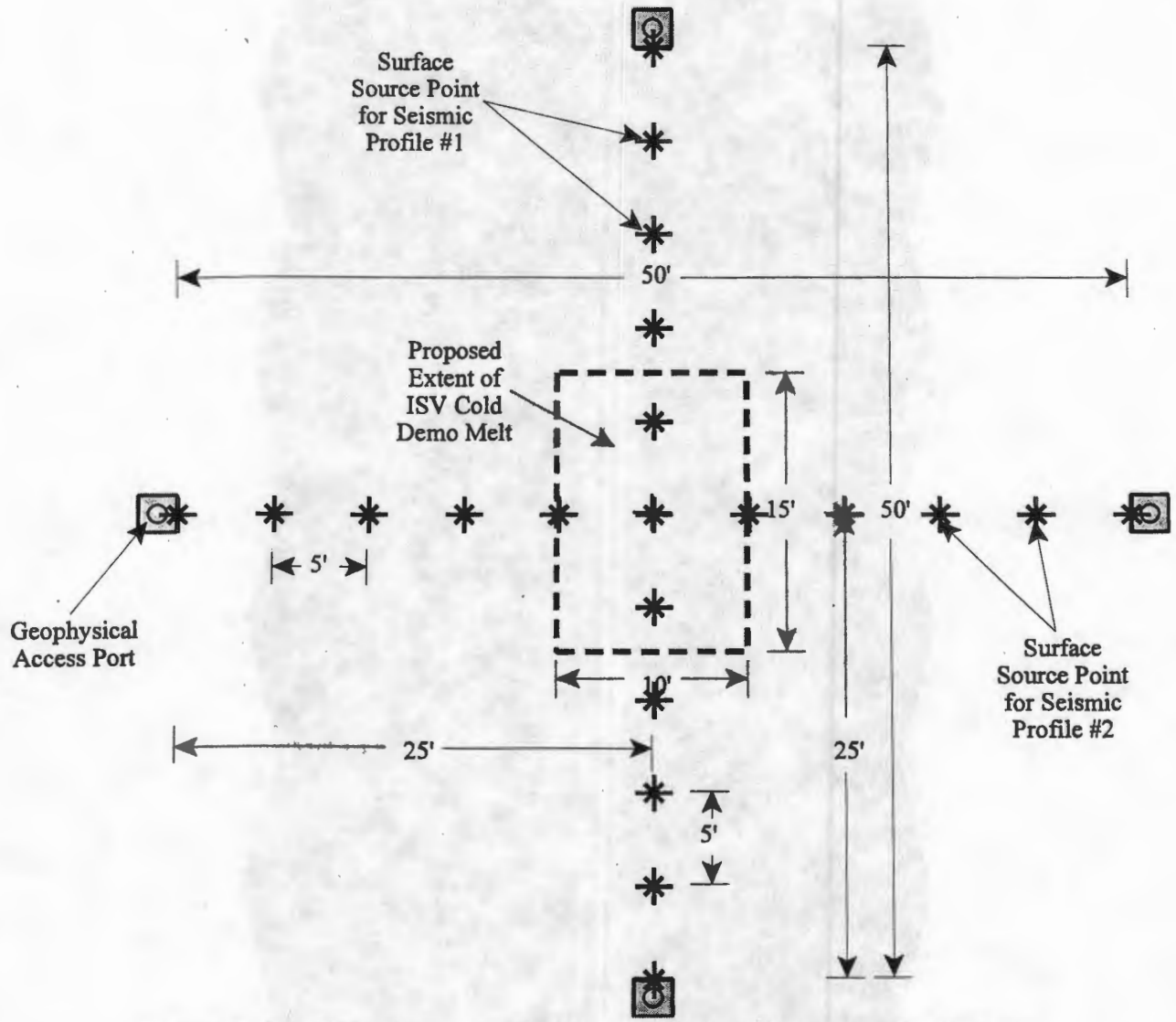


Figure 5. Profiles and Source Positions for Seismic Tomography Surveys

filled with potable water to approximately 2 ft bgs prior to placing the receivers into the ports. The water is necessary to provide a coupling medium between the receivers and the surrounding formation. Travel times will be recorded along the length of the boreholes for each surface source position. The surface source locations will be surveyed for x, y, and z locations following the data acquisition to provide accurate distances from source to receivers.

3.1.2. Baseline Seismic Velocity Tomography Data Processing

Baseline seismic velocity data will be processed as two profiles. Travel times and distances will be determined for each source receiver pair to create the tomography data set. Seismic tomography data will be processed using GEOTOMAN, a computer program developed for three-dimensional tomographic imaging. Straight ray and curved ray processing will be employed in the inversion of the travel time data. When the inversion process is completed, a tomographic section, showing seismic velocity distribution, will be produced for each profile.

3.2. Baseline Ground Penetrating Radar (GPR) Tomography

Borehole to borehole and surface to borehole GPR data will be acquired to determine the GPR velocity distribution in the subsurface and test trench prior to the ISV melt. Baseline data will be used to distinguish GPR velocity anomalies resulting from the melt process from those which are original features in the subsurface.

3.2.1. Baseline Ground Penetrating Radar (GPR) Tomography Data Acquisition

Borehole to borehole GPR data will be acquired along the two planes between the access port pairs spaced 50 feet apart (See Figure 6.) Prior to taking the borehole GPR data, the boreholes any water in the boreholes will be remover and disposed of. Because of the borehole construction, any water removed from the boreholes is not expected to be contaminated and therefore should not pose a disposal hazard to either human health or the environment. A transmitting antenna will be at a fixed depth in one borehole and a receiver antenna will be moved in increments of 3.28 feet (1 meter) along the length of the opposite borehole. When finished, the transmitting antenna will be lowered 3.28 feet (1 meter) and the process repeated.

Surface to borehole GPR data will be acquired along the two planes between the access port pairs spaced 50 feet

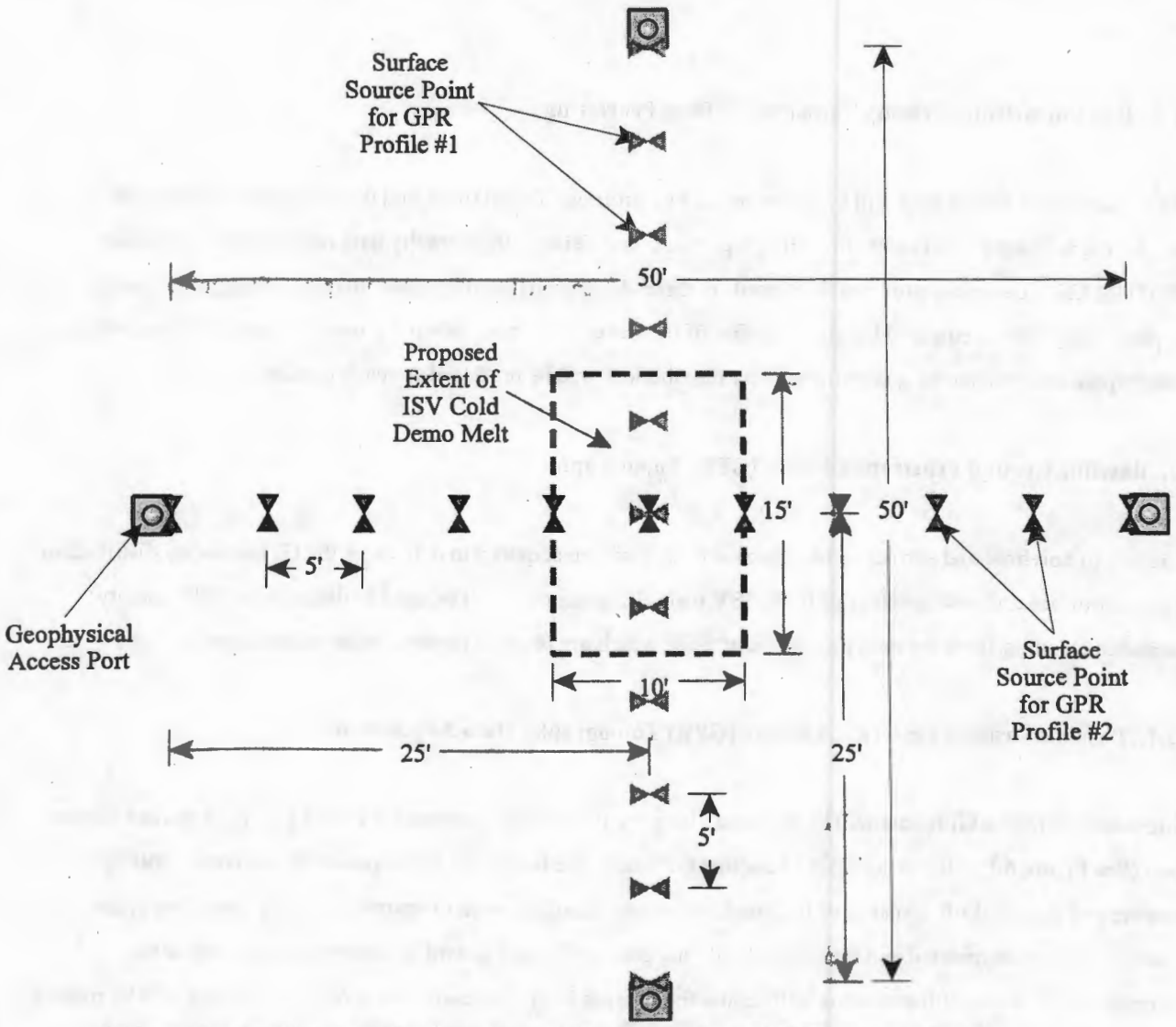


Figure 6. Profiles and Surface Source Positions for GPR Tomography Surveys

apart. (See Figure 7.) A transmitting antenna will be positioned between each access port pair at a 5 foot increment. Surface antenna positions will be surveyed for x, y, and z locations. A receiver antenna will be placed in each geophysical access port and moved in increments of 3.28 foot (1 meter) along the length of the borehole. Travel times will be recorded along the length of the boreholes for each surface source position.

3.2.2. Baseline Ground Penetrating Radar (GPR) Tomography Data Processing

Baseline GPR velocity data will be processed as two profiles. Travel times distances will be determined for each surface to borehole and borehole to borehole source receiver pair to create the tomography data set. GPR tomography data will be processed using GEOTOMAN. When the inversion process is completed, a tomographic section, showing the GPR velocity distribution, will be produced for each profile.

3.3. Baseline Electrical Resistance Tomography (ERT)

Borehole to borehole ERT data will be acquired to determine the electrical resistance distribution in the subsurface and test trench prior to the ISV melt. Baseline data will make it possible to determine if electrical resistivity anomalies are a result of the melt process or an original feature.

3.3.1. Baseline Electrical Resistance Tomography (ERT) Data Acquisition

Borehole to borehole ERT data will be acquired along the two planes between the access port pairs spaced 50 feet apart. (See Figure 8.) Electrodes emplaced with the access ports will be used to inject electrical current into the subsurface and measure the resulting electrical potentials. Electrode source pair and receiver pair configurations will be varied, based on the forward ERT modeling results, until a sufficient data set is acquired.

3.3.2. Baseline Electrical Resistance Tomography (ERT) Data Processing

Baseline ERT data, including current measurements, potential measurements, and dipole locations, will be inverted using OCC2D3D v1.0. OCC2D3D allows the forward and inverse modeling of electrical resistivity and induced polarization (IP) data. Two tomographic sections will be generated from the baseline ERT data.

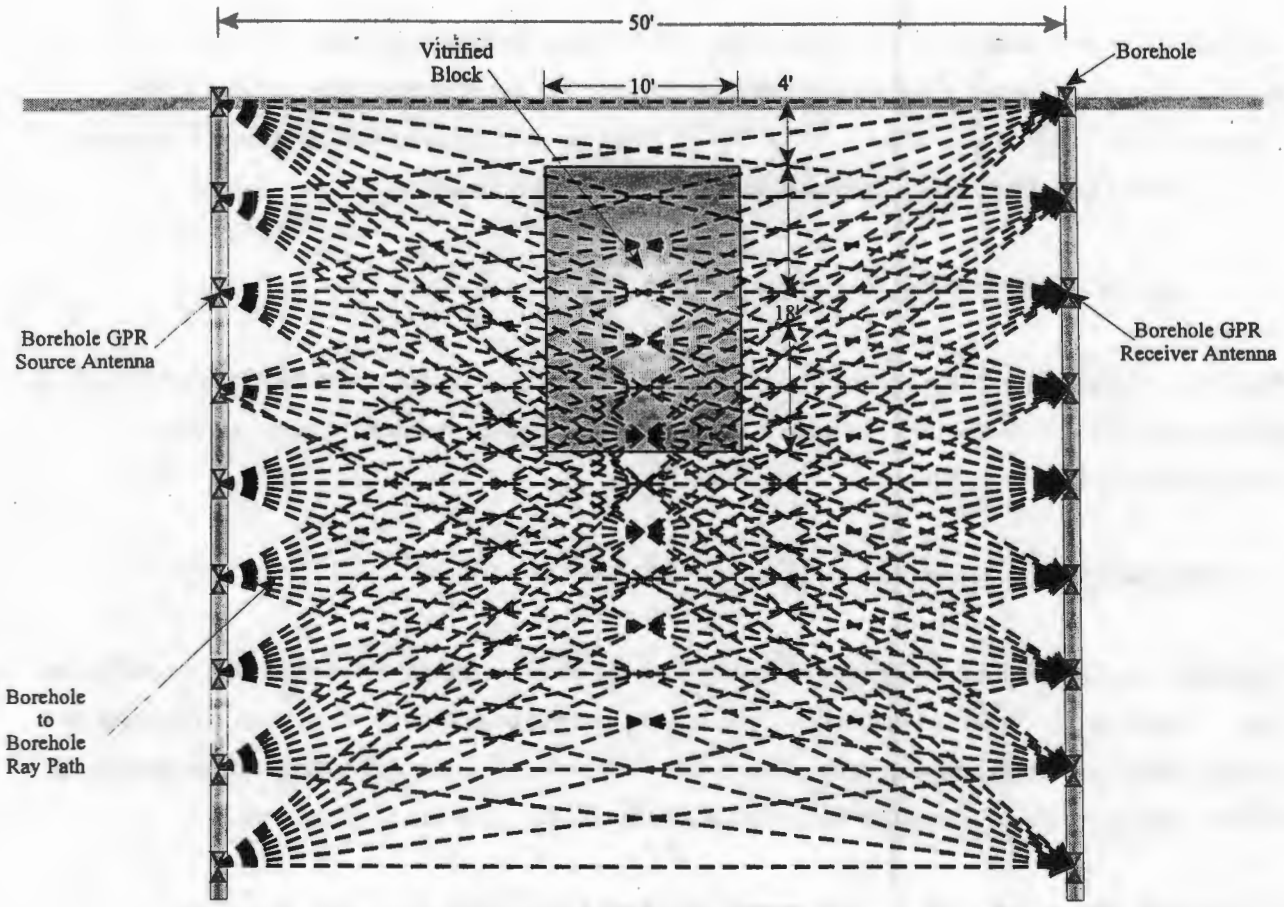


Figure 7. Borehole to Borehole Setup for GPR Tomography Surveys

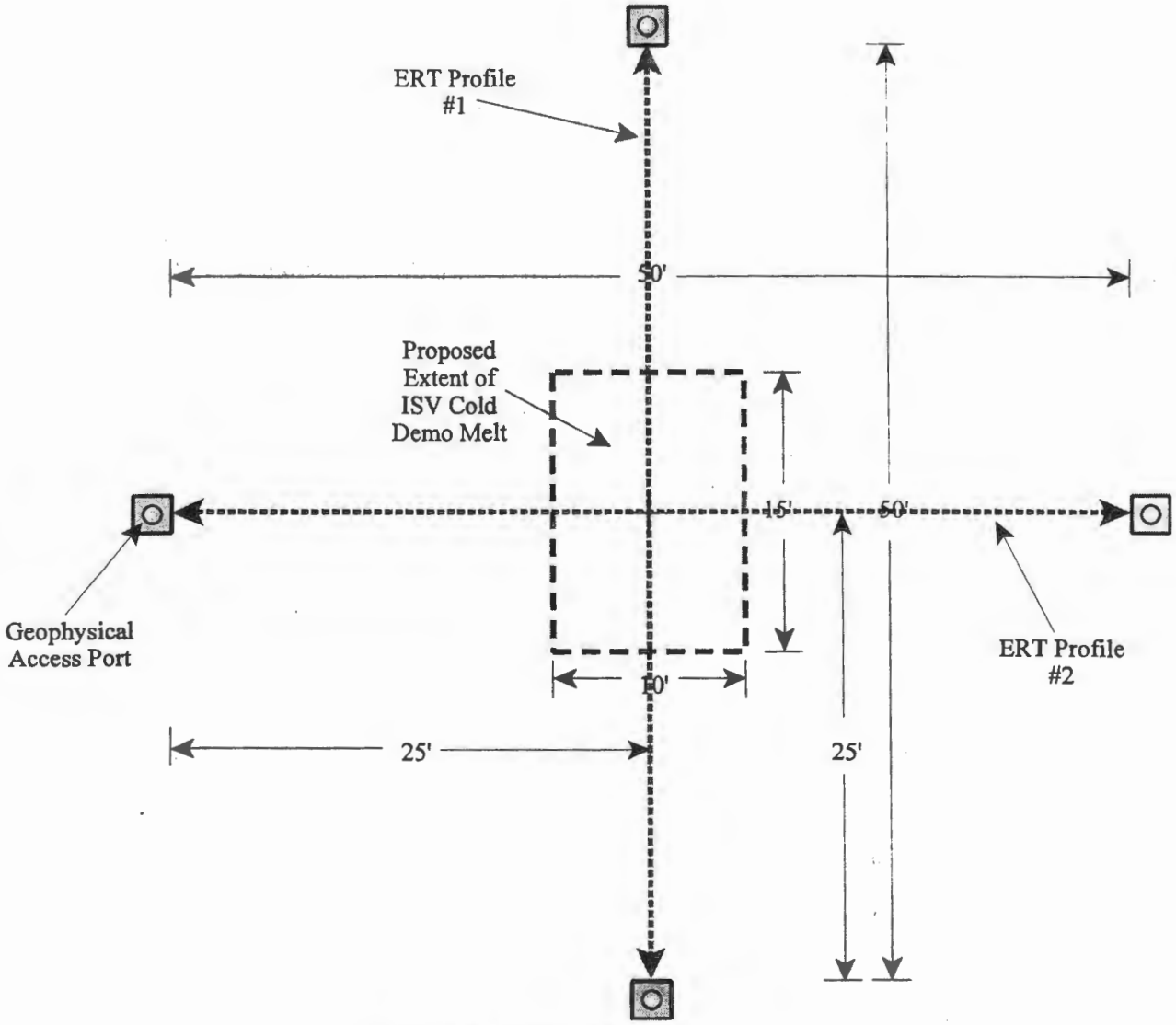


Figure 8. Profiles for ERT Survey

4. GEOPHYSICAL MONITORING OF ISV MELT (OPTIONAL)

During the ISV process it may be possible to acquire geophysical data to monitor the progress and condition of the melt. Geophysical monitoring of the ISV melt will depend primarily upon the site conditions, including:

- Extents of the exclusion zone;
- Access to geophysical access ports;
- Amount of physical noise (trucks, heavy equipment, construction activities, etc.); and
- Amount of electrical noise (generators, power lines, etc.);

Equipment for acquiring the geophysical data during the melt will be available if it is determined that sufficient and useful data can be acquired.

5. GEOPHYSICAL POST-MELT ASSESSMENT

The post-melt data acquisition will begin after the off-gas collection hood has been removed and the site has been re-graded. Ideally, these activities will be completed while the ISV block is molten. The data acquisition will parallel the pre-melt data acquisition described in Section 3 of this work plan. The data will include surface to borehole seismic, borehole to borehole electrical resistivity, and borehole to borehole and surface to borehole GPR data

5.1. Post-Melt Seismic Velocity Tomography

Surface to borehole seismic tomography data will be acquired, after the ISV Cold Demonstration melt is completed, in an effort to map the size, shape, and extents of the vitrified block. Results will be compared to the dimensions determined from the excavation activities planned for the Cold Demonstration to determine if seismic travel time tomography is a valid method for non-destructively estimating the size and shape of the monolith.

5.1.1. Post-Melt Seismic Velocity Tomography Data Acquisition

Post-melt seismic tomography data will be acquired using the same configuration and procedures used for the

baseline data acquisition. The boreholes will be filled with water to within approximately 2 ft bgs to provide the coupling of the receivers tot he formation. Surface to borehole seismic data will be acquired along the two planes between the access port pairs spaced 50 feet apart. (See Figure 5.) A seismic source will be positioned between each access port pair at a 5 foot increment. Seismic receivers, spaced 1 foot apart, will be placed in each geophysical access port. Travel times will be recorded along the length of the boreholes for each surface source position.

5.1.2. Post-Melt Seismic Velocity Tomography Data Processing

The processing techniques used for the baseline seismic tomography data will be used for the post-melt seismic tomography data. Post-melt seismic velocity data will be processed as two profiles. Travel times and distances will be determined for each source receiver pair to create the tomography data set. Seismic tomography data will be processed using GEOTOMAN. When the inversion process is completed, a tomographic section, showing seismic velocity distribution, will be produced for each profile.

Post-melt seismic velocity tomograms will be compared to the corresponding baseline tomograms. A difference tomogram generated from the post-melt data and the baseline data will highlight seismic velocity changes in the subsurface resulting from the ISV process.

5.2. Post-Melt Ground Penetrating Radar (GPR) Tomography

Surface to borehole and borehole to borehole GPR tomography data will be acquired, after the ISV Cold Demonstration melt is completed, in an effort to map the size, shape, and extents of the vitrified block. Results will be compared to the dimensions determined from the excavation activities planned for the Cold Demonstration to determine if GPR travel time tomography is a valid method for non-destructively estimating the size and shape of the monolith.

5.2.1. Post-Melt Ground Penetrating Radar (GPR) Tomography Data Acquisition

Post-melt GPR tomography data will be acquired using the same techniques used for the acquiring the GPR baseline data acquisition. Any water in the boreholes will be pumped out and disposed of properly. Borehole to borehole

GPR data will be acquired along the two planes between the access port pairs spaced 50 feet apart. (See Figure 7.) A transmitting antenna will be at a fixed depth in one borehole and a receiver antenna will be moved in increments of 3.28 feet (1 meter) along the length of the opposite borehole. When finished, the transmitting antenna will be lowered 3.28 feet (1 meter) and the process repeated.

Surface to borehole GPR data will be acquired along the two planes between the access port pairs spaced 50 feet apart. (See Figure 6.) A transmitting antenna will be positioned between each access port pair at a 5 foot increment. A receiver antenna will be placed in each geophysical access port and moved in increments of 3.28 feet (1 meter) along the length of the borehole. Travel times will be recorded along the length of the boreholes for each surface source position.

5.2.2. Post-Melt Ground Penetrating Radar (GPR) Tomography Data Processing

Post-melt GPR velocity tomograms generated using GEOTOMAN will be compared to the corresponding GPR baseline tomograms. A difference tomogram generated from the post-melt data and the baseline data will highlight GPR velocity changes in the subsurface resulting from the ISV process.

5.3. Post-Melt Electrical Resistance Tomography (ERT)

Borehole to borehole seismic ERT data will be acquired, after the ISV Cold Demonstration melt is completed, in an effort to map the size, shape, and extents of the vitrified block. Results will be compared to the dimensions determined from the excavation activities planned for the Cold Demonstration to determine if ERT is a valid method for non-destructively estimating the size and shape of the monolith.

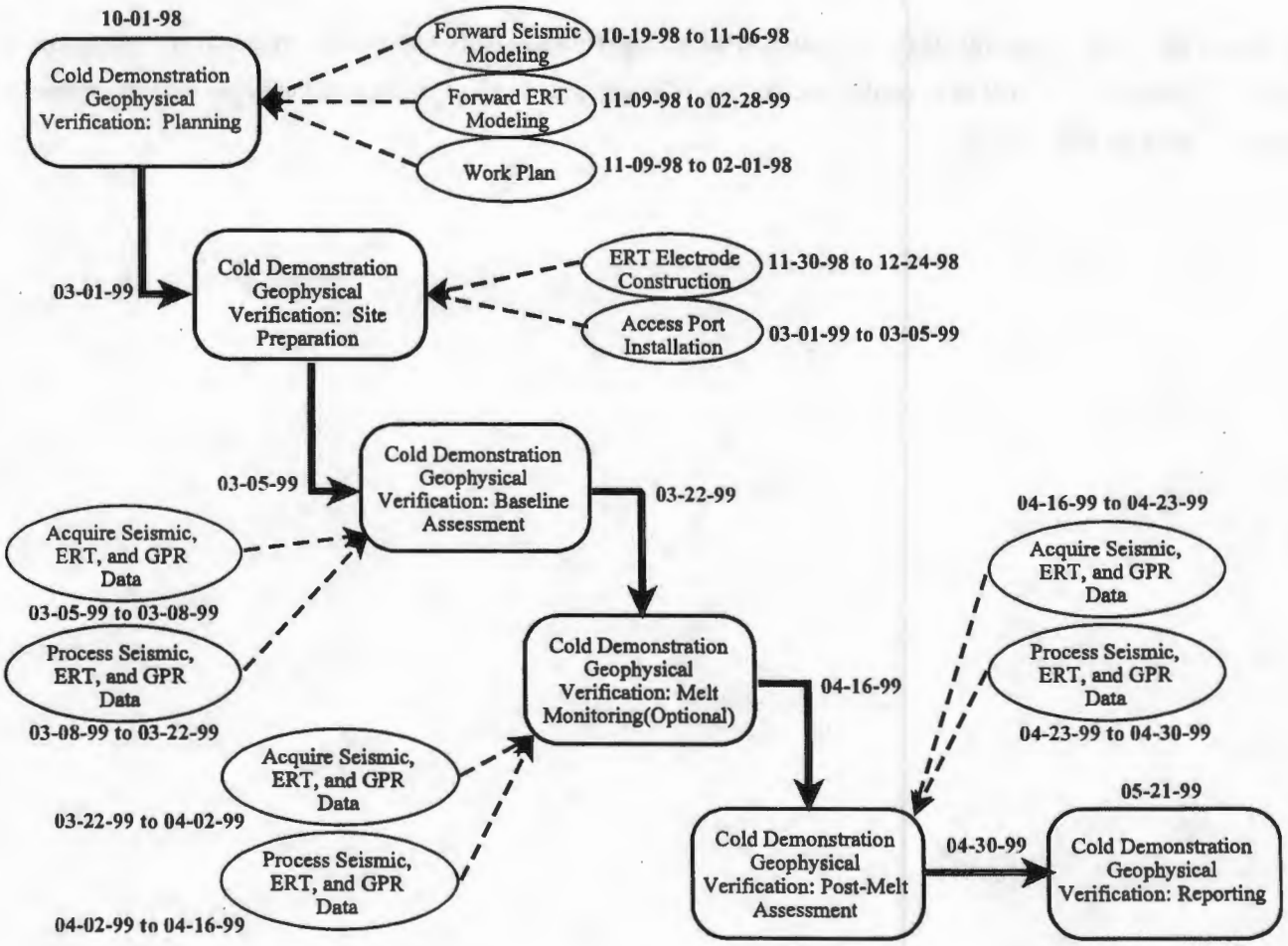
5.3.1. Post-Melt Electrical Resistance Tomography (ERT) Data Acquisition

Post-melt ERT data will be acquired using the same electrode configurations used for the baseline ERT data acquisition. Borehole to borehole ERT data will be acquired along the two planes between the access port pairs spaced 50 feet apart. (See Figure 8.) Electrodes emplaced with the access ports will be used to inject electrical current into the subsurface measure the resulting electrical potentials. Electrode source pair and receiver pair configurations will be varied, based on the forward ERT modeling results, until a sufficient data set is acquired.

5.3.2. Post-Melt Electrical Resistance Tomography (ERT) Data Processing

ERT data, collected after the ISV Cold Demonstration melt is completed, will be processed using the same methods used to process the ERT baseline data. Post-melt ERT data, including current measurements, potential measurements, and dipole locations, will be inverted using OCC2D3D v1.0. Two tomographic sections will be generated from the post-melt ERT data.

Post-melt ERT tomograms will also be compared to the corresponding baseline tomograms. A difference tomogram generated from the post-melt data and the baseline data will highlight electrical resistance changes in the subsurface resulting from the ISV process.

6. SCHEDULE

The verification activities proposed will follow the schedule shown below. This schedule has been developed to parallel other activities related to this NTISV Cold Demonstration. Changes to this schedule or the schedules of the other demonstration activities must be coordinated to prevent delays in the project and or the simultaneous scheduling of incompatible activities.