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REVISION 0

FINAL REPORT

FOR THE

**DEMONSTRATION OF PLASMA IN-SITU VITRIFICATION
AT THE 904-65G K-REACTOR SEEPAGE BASIN (U)**

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Does Not Contain Unclassified Nuclear Information

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LIST OF ABBREVEATIONS

°C	Degrees Celsius
DC	Direct Current
EPA	Environmental Protection Agency
ERD	Environmental Restoration Department
°F	Degrees Fahrenheit
ft.	Feet
GIT	Georgia Institute of Technology
GPR	Ground Penetrating Radar
in	Inches
ISV	In Situ Vitrification
kW	Thousand Watts of electrical power
kW-h	Thousand Watt-hours of electrical energy
lb	Pounds
MW	Million Watts
PCT	Product Consistency Test
SRS	Savannah River Site
SRTC	Savannah River Technology Center
WSRC	Westinghouse Savannah River Company

EXECUTIVE SUMMARY

The In-situ Vitrification (ISV) process potentially offers the most stable waste-form for containment of radiologically contaminated soils while minimizing personnel contamination. This is a problem that is extensive, and at the same time unique, to the US Department of Energy's (DOE) Weapons Complex. An earlier ISV process utilized joule heating of the soil to generate the subsurface molten glass product. However previous test work has indicated that the Savannah River Site soils (SRS) may not be entirely suitable for vitrification by joule heating due to their highly refractory nature. The concept of utilizing a plasma torch for soil remediation by in-situ vitrification has recently been developed, and laboratory test work on a 100kW unit has indicated a potentially successful application with SRS soils. The Environmental Restoration Division (ERD) of Westinghouse Savannah River Company (WSRC) conducted the first field scale demonstration of this process at the (904-65G) K-Reactor Seepage Basin in October, 1996 with the intention of determining the applicability and economics of the process for remediation of an SRS radioactive seepage basin.

The demonstration was successful in completing three vitrification runs, including two consecutive runs that fused together adjacent columns of glass to form a continuous monolith. This report describes the demonstration, documents the engineering data that was obtained, summarizes the process economics and makes recommendations for future development of the process and equipment.

DEMONSTRATION OF PLASMA IN-SITU VITRIFICATION AT THE (904-65G) K-REACTOR SEEPAGE BASIN (U)

1.0 INTRODUCTION

Vitrification has long been accepted as producing the most durable waste form for preventing the release of radioactivity from contaminated soils. Vitrifying contaminated soil in-situ rather than the alternative process of exhumation followed by remote ex-situ processing, presents the additional advantage of minimizing the spread of contamination. In-situ vitrification (ISV) by 'top down' joule heating of soil has been under development for a number of years at Hanford, and has achieved commercial deployment by GEOSAFE Corporation at Hanford, Oak Ridge and other domestic and foreign locations. However previous test work¹ has shown that the soils at the Savannah River Site (SRS) are highly refractory in nature and are difficult to vitrify by joule heating. In addition the water table levels at SRS are much closer to the surface than are generally found in the western regions of the country and make 'top down' joule heating more susceptible to high energy steam expulsion events. Therefore a very high temperature bottom to top or 'bottoms up' direction of heating, which would also incorporate a method of gas release, would be more suitable for ISV of candidate waste units at SRS as well as other eastern locations.

To undertake preparatory work for the potential application of ISV at an SRS waste unit, the Savannah River Technology Center (SRTC) had begun investigating the possibility of utilizing a plasma torch for 'bottoms up' ISV and had funded pilot plant scale testing² at the Georgia Institute of Technology (GIT). By the spring of 1996, the GIT work had indicated that the process was potentially viable for vitrification of SRS soils, including a test in a simulated high water table situation. However, the process needed to be validated at a clean site, at a near production scale, before deployment into a radioactive environment could be contemplated. The Environmental Restoration Division (ERD) of Westinghouse Savannah River Company (WSRC) organized this demonstration at a clean location adjacent to the (904-65G) K-Reactor seepage basin with the multiple objectives of:

- Developing realistic cost/effectiveness data for evaluation of the process against other competing remediation technologies such as soil grouting or deployment of a RCRA type cover system.
- Making an engineering assessment of the current state of development of the technology, which would provide a basis for estimating the amount of future development work that would be required to make the process commercially viable.
- Developing the engineering data necessary for possible subsequent full-scale deployment at an SRS radiologically contaminated waste unit.
- Evaluating commercially available non-intrusive subsurface monitoring techniques as potential methods for regulatory compliance verification.

In order to vitrify the soil in an SRS basin, within a reasonable time frame and in a full scale operating mode, a plasma torch of at least 1MW power level would be required. A portable 1MW plasma torch, manufactured by Plasma Energy Corporation of Raleigh NC, was available, and was leased for the duration of the demonstration along with technical support from Hydro-Quebec of Montreal, Canada. GIT provided additional support on subsurface geophysics, with offgas measurements being made by Clemson University and supplemental process control instrumentation being provided by the Equipment Engineering Section of SRTC.

This report provides a description of the demonstration with documentation of the engineering data obtained. It also makes recommendations for the path forward based on observations made during the period of the demonstration.

2.0 PROCESS DESCRIPTION

In operation, a non-transferred arc plasma torch passes a high voltage, high current DC arc between two electrodes located at the tip of the hollow torch barrel. At the same time, a flow of air or inert gas is passed down through the hollow barrel and through the arc. The atoms in the air are ionized as they pass through the arc and emerge from the torch nozzle with a 'flame' temperature in excess of 5,000 °C. These temperatures are sufficient to vitrify SRS soils, which have a melting temperature of around 1,800 °C. Due to the very high temperatures, the type of torch used in the demonstration utilized a water cooled barrel to prolong the life of its components.

When using the ISV process in a radioactive environment, a layer of clean soil is first placed over the contaminated waste layer or basin floor. A hole is then drilled or punched down through the soil past the bottom of the waste layer waste layer, with a diameter slightly larger than the torch barrel. The torch is then inserted into the hole, nearly down to the bottom, and then ignited. As the soil melts its volume contracts and a cavity is formed which contains molten glass in the lower half and a space for the torch 'flame' in the top half. The torch is slowly withdrawn up through the waste layer, melting the soil thus producing a column of glass which contains virtually all of the contamination. The torch is extinguished when the cavity has passed through the waste layer and all the contaminated soil has been vitrified. The resulting glass column is some 3ft to 5 ft in diameter, depending on the torch power level, and to vitrify a larger area, the process is repeated on a spacing such that the glass column peripheries overlap.

The offgas from the torch exits up through the annulus between the torch barrel and the hole. Atmospheric pressure is maintained at all times in the subsurface cavity and the possibility of a rapid steam expulsion event is virtually non-existent. Due to the very high temperatures involved, the offgas from treating radioactive waste would contain a small portion of the radionuclides that volatilize at the process operating temperatures, which then have to be captured by a hood placed over the hole. The captured offgas would have to be cleaned by quenching, scrubbing and filtration to maintain an overall radionuclide capture efficiency of 99.99% or better. However as this demonstration was conducted in a clean area, calculations indicated that emissions would consist of de-minimis levels of particulates and criteria pollutants, and an internal air permit was obtained from the Environmental Protection Department of WSRC. Due to the practical difficulties of making offgas measurements in the field using the delicate EPA Method 29 apparatus, the concentrations of cesium and strontium in the offgas were measured by Clemson University at the GIT pilot plant using SRS soils that had been doped with Cs and Sr non-radioactive Cs and Sr simulants.

3.0 DEMONSTRATION TECHNICAL CRITERIA

In the event that the process would be eventually deployed at an SRS radioactive basin, the ideal location for the clean demonstration would be in close proximity to a potentially suitable waste unit. A number of radioactive basins were surveyed and the (904-65G) K-Reactor Seepage Basin was selected as a preferred location for the first deployment of this technology in a radioactive environment. Selection criteria included such factors as proximity to an adequate power supply, height of water table, accessibility, waste unit area, contamination level and type etc. The clean demonstration was therefore set up in an area to the west of the K-Reactor Seepage Basin.

This demonstration represented a scale up in power level over the GIT work by a factor of 10, hence the process performance parameters had to be determined before an attempt could be made to create a monolith from several glass columns. These process parameters were:

- The diameter of the subsurface cavity and the diameter of the glass column had to be determined at the 1MW power level along with the factors that controlled this dimension namely torch operating power level, torch withdrawal rate and torch nozzle height above melt.
- The PEC plasma torch nozzle must be maintained at fairly constant distance above the melt and at no time can be allowed to contact the melt. At GIT, this was accomplished visually, but in any future operations at a contaminated waste unit, this must be accomplished accurately and consistently from a remote location. Therefore it was considered essential to assess candidate instrumental techniques which could accurately monitor melt level and control the torch position before a full scale deployment into a radioactive location could be contemplated. During this demonstration, a combination of ultrasonic distance measurement, Time Domain Reflectometry and soil temperature measurements using thermocouples were tried. As a back up precaution, these methods were verified during the demonstration by manual probing of the melt level.
- Glass quality and resistance to leaching.
- Determination of the partition coefficients for the contaminants in the soil between the glass and the offgas. This data would be essential for the design and permitting of the offgas system for the full scale deployment in a contaminated application.
- If this process is eventually deployed in a CERCLA waste unit closure action, regulatory agencies will require QA of vitrification effectiveness. Therefore, non-intrusive methods for determining the extent of penetration of the vitrified mass into the waste layer must be proven before this technology can be capable of a commercial deployment. A variety of non-intrusive geophysical methods were deployed before at the demonstration site to profile the subsurface vitrified masses, including ground penetrating radar (GPR), cross-hole seismic surveying, surface resistivity, electromagnetic and magnetometer surveys.

4.0 SEQUENCE OF EVENTS

The events for field operations are described in WSRC-RP-96-00834, the Technical Task Plan for the demonstration (see Appendix A).

Before any work was done at the demonstration site, GIT performed the geophysical surveys to establish baseline soil characteristics. The geophysical measurements were made over a 50 ft square grid which encompassed the demonstration site. In addition, Shelby tube samples were taken in the borehole vicinity to determine soil chemical and physical characteristics.

A total of three vitrification runs were made and a column of soil was successfully vitrified each time. Run #1 was used to assess how the torch system operated and to determine the principal operating parameters that affected the vitrified product size and quality. Runs 2 and 3 were made using the optimized operating parameters from run #1. Run #3 was a repeat of run #2 but was an attempt to coalesce the columns from runs #2 and #3 together.

The torch barrel was only 4 ft long, which limited insertion depth of the torch nozzle to of 3ft-6ins. Starter holes of 10 in diameter were bored on 10 ft centers to a depth of approximately 7 ft to allow for initial glass column development at the bottom of the hole. The holes were lined with thin gage steel tubing to prevent sidewall collapse and were flanged at ground level. The first run had the steel liner extending to the bottom of the hole, while in runs #2 and #3 the holes were lined to just 1 ft below grade level. After run #2, the diameter of the vitrified subsurface product was estimated to be about 3ft-6ins in diameter by probing with a steel rod. The starter hole for run #3 was bored to a depth of 7 ft on a 3 ft spacing from the hole for run #2. During each run, the subsurface cavity was allowed to come within 6ins of the ground surface before the run was terminated.

The torch was supported on an overhead gantry/platform which served to allow for adjusting the height of the torch and taking measurements during operation. No personnel were permitted inside a 50 ft square Exclusion Zone around the torch unless the system electrical lock-out was in place. A selection of photographs of the demonstration site, the torch in operation and a vitrified monolith are given in Appendix G.

5.0 RESULTS

5.1 Vitrification Runs

A total of three runs were made and a column of soil was successfully vitrified each time. Each run started out at around the 600 kW power level and ramped up through the run as the subsurface cavity developed. Each run was interrupted fairly frequently to inspect the torch front electrode and replace the front o-ring if necessary. Run #1 utilized an average power level of 750kW with a total run time of 40 minutes. This run produced a fairly narrow glass column. Operating time during run #2 was 105 minutes at an average power level of 680kW and produced a wider glass column estimated to be between 3 and 4 ft in diameter. Total run for run #3 time was 95 minutes which operated with an average power level of 650 kW for the first 40 minutes and then was ramped up to, and was held at 900 kW for the last 30 minutes. A graphical representation of the principal torch parameters for run #3 is given in Appendix F.

The three melts were exhumed after the demonstration and were measured and weighed. Melt geometries are shown in Appendix B and the weights were 600 lb for melt #1, 1100 lb for melt #2 and 1150 lb for melt #3. Visual observation indicated that melts #2 and #3 had achieved contact with no un-vitrified material at the contact faces, however glass fusion at the interface did not occur.

The torch cooling water temperature is the critical parameter which determines longevity of the front o-ring. O-ring failure occurred when the torch water exit temperature exceeded 38 °C.

5.2 Melt Level Monitoring

Maintaining the torch nozzle at a consistent elevation above the melt was a critical parameter in torch operation. The torch front electrode had to remain clear of the melt in order to function. The torch nozzle height and withdrawal rate appeared to have a significant effect on the heat transfer rate to the molten glass. Controlling the electrode height above the melt to a minimum by optimizing the torch withdrawal rate, appeared to produce larger diameter and more regular glass monoliths. During run #1, the torch nozzle was maintained at a height of 30ins above the melt, and with an average withdrawal rate of 0.75 in/minute which produced a narrow irregular melt with a maximum diameter of 2ft-1in at the top. Runs #2 and 3 utilized 24 and 18 in separation between the torch nozzle and the glass with withdrawal rates of 0.28 and 0.22 in/minute respectively. Melt diameters were 2ft-6in and 3ft-6in respectively.

Cavity growth was determined by a 3-D thermocouple array in runs #2 and #3. Down hole ultrasonic monitoring was deployed during runs #2 and #3 and Time Domain Reflectometry was deployed during run #3. Ultrasonic monitoring and time domain reflectometry were intended to detect the melt level. A description of these technologies and method of their application is given in Appendix E. Time Domain Reflectometry worked well in detecting the elevation of the roof cavity. The ultrasonic melt level detector survived the hot environment above the hole opening, but gave inaccurate measurements possibly due to reflections from the offgas offtake, hole casing and air temperature variations in the hole. The thermocouple array detected the position of the cavity roof and walls but not the melt level. Only manual

probing successfully detected the melt level. The arrangement of the thermocouple array is given in the workplan in Appendix A.

5.3 Torch Performance

5.3.1 Energy Consumption

During the three demonstration runs, a total of 4033 kW-h of energy was used to produce a total glass weight of 3050 lbs. This equates to an average energy usage of 1.32 kW-h/lb of glass. Power consumption was measured at the substation and includes all transformer, torch power supply and cooling system losses.

A torch that possessed a wider range of power turndown than the 2:1 of the PEC unit, would be highly desirable. The minimum operating power level of 600kW appeared to be excessive at the start of a burn, but after the cavity was fully formed, continuous operation at the 900kW power level or greater appeared to be viable.

Total energy loss into the cooling water was high and exceeded 40% of the total electrical power towards the end of a run. This was not all waste energy but included heat transferred to the torch front electrode from heat radiated up from the melt and from hot gasses passing between up the annulus surrounding the torch barrel.

5.3.2 Electrode Wear

Electrode wear was estimated by physically measuring the depth of erosion on the front electrode and comparing with the amount of metal that was available with a new front electrode assembly. About ¼ to ⅓ of the torch front electrode appeared to be consumed at the end of the demonstration which amounted to about 5 hours total run time, including open air test firing. This indicated that a front electrode life of about 20 hours could be expected under similar conditions to the demonstration. Both Hydro-Quebec and PEC believe that the back pressure generated by down hole firing to be responsible for disturbing the vortex in the torch air tube which distributes the arc over the electrode surfaces. This is a very short life for commercial operation in a radioactive environment where the high manual maintenance manhours would result in high worker exposure conditions.

5.3.3 Torch Reliability

The design of this particular PEC torch is at least 15 years old and clearly suffered from inadequate heat dissipation from around the nozzle which caused rapid o-ring failure. According to PEC, this particular torch was not designed to handle the additional heat transfer load imposed by blow back of the hot gases past the nozzle area. More recent PEC torch models have been deployed in steel plant applications where similar blow back situations exist and have been designed with greater heat dissipation capacity in the nozzle area.

The o-rings used by Hydro-Quebec were thought to be a mixture of Buna-N and Viton rubber which have maximum service ratings of 200 °F and 400 °F respectively. Visual inspection revealed that these o-rings failed by softening, which would indicate that the service temperature was only marginally exceeded. Kalrez o-rings have a service limit of 600 °F and would be more suitable in any further work.

The torch was not originally designed to be suspended vertically over the hot zone, and a number of torch components at the back of the torch were made of plastic which were vulnerable to hot gases generated by the process which rose vertically. At the end of the demonstration, the torch outer casing at the nozzle

was found to have become slightly distorted, due to overheating and internal stress relief within the stainless steel tube material, which made disassembly of the electrode assembly difficult. These components, along with some other torch materials, must be upgraded before the system could be deployed on an industrial basis in a radioactive application.

5.4 Glass Leachability

The detailed analysis of glass leachability is given in Appendix B. To summarize the leach rate of silicon into the leachate during a standardized Product Consistency Test was several orders of magnitude better than the rate typically obtained for the DWPF Environmental Assessment (EA) glass.

5.5 Offgas Measurements

Due to the multitude of practical difficulties in making offgas measurements in the field with the delicate EPA apparatus, these measurements were made during a special offgas run at the GIT Plasma Test Facility in Atlanta. SRS soil was doped with non radioactive CsCl and $\text{Sr}(\text{NO}_3)_2$ at concentrations of Cs^+ equal to 9.8ppm and Sr^{++} equal to 9.9ppm respectively. Concentrations of these elements in the K-Reactor seepage basin soils are in the ppb range. However reproducing such low concentrations in the test batch of soil would have been impractical, therefore the concentrations were raised to the 10ppm range for the offgas test.

The offgas run was made using the GIT 100 kW torch with 556 lb of artificially contaminated soil in a 55 gallon drum in the GIT plasma research facility in Atlanta. Offgas measurements were made by Clemson University by EPA Method 29. The plasma torch run lasted 80 minutes and the offgas was sampled over 60 minutes. The material balance of was averaged over the 60 minute run time and resulted in a capture efficiency to the glass of 99.876% for the Cs and 99.998% for the Sr. The full calculation and the back up data is given in Appendix C.

5.6 Subsurface monitoring by geophysical methods

In any full scale deployment of this technology in a waste unit, post installation verification of the percent completion of the vitrification process will be essential in obtaining closure certification from the environmental regulatory agencies. In a full scale basin closure, the vitrified waste monolith will be made up from a large number of glass columns. Verifying that contact between the multiple glass columns is complete and that only minimal unvitrified product remains between the interstices will be of paramount importance in compiling the basin closure QA documentation. Verification is especially important with the first deployment of any new technology where there is only minimal operating history from which to draw to provide performance verification data. As only non-intrusive monitoring techniques will be able to be applied to a vitrified waste unit, a number of geophysical techniques were tested during the K-Reactor seepage basin test. Geophysical surveys were made over the 50' square test area before and then after the vitrified columns were created. Results were presented graphically and examined to determine if the resolution was sufficient to detect discrepancies in the geometry of the vitrified mass.

The geophysical techniques deployed by GIT during the trial were:

- Cross hole seismic surveying.
- Ground penetrating radar (GPR).
- Surface electrical resistivity surveys
- Electromagnetic conductivity surveys.
- Magnetometer surveys.
- Temperature measurement by thermocouple array.

Results of the geophysical testing as well as some initial site characterization work are given in Appendix D. To summarize, only the GPR and Spectral Analysis of Surface Waves gave any indication of the presence of the double columns (but not the single) at all. Even though the presence of the vitrified masses was detected, the resolution was not precise enough to detect discontinuities and was considered to be inadequate for post installation QA purposes.

6.0 ECONOMIC EVALUATION

It is very difficult to establish realistic costs for a full scale deployment of plasma ISV from this relatively short demonstration. However a comparison can be made between vitrification and conventional technologies based on available published data.

<u>CLOSURE METHOD</u>	<u>INSTALLATION COST</u>	<u>DURABILITY</u>
RCRA type cover ³	\$25 - \$50/sq ft (\$100 to \$200/ton)	up to 100 years
In-situ solidification and stabilization ⁶	\$150 - \$250/ton	up to 200 years
In-situ vitrification ⁵	\$350 - \$750/ton	>5000 years

The cost of vitrification is based on published data from GEOSAFE Corporation for their 'top down' method of soil melting utilizing joule electrode heating⁵. By comparing the various components of this cost between plasma and joule melting, a qualitative comparison of the relative costs of the two methods can be made. The capital costs of both melt systems are probably similar as the electrical power supplies, offgas collection, electrode and torch systems etc would be of basically the same size. Power costs are probably also comparable. By melting down from the surface as in the GEOSAFE process, all the clean surface soil must be melted in order to vitrify the subsurface contamination layer. It is possible that power can be saved by 'bottom-up' plasma arc melting through the waste layer only. However due to cooling water losses, the power consumption of the plasma torch is at least 30% higher than the published⁶ data obtained for joule melting trials of SRS soils, therefore any potential savings would probably not be realized. Infrastructure and support costs might be higher for plasma melting due to the smaller diameter of the melt zone, which would necessitate many more initial soil borings and relocations of the torch than with the GEOSAFE process which would have a melt zone of about 10 ft in diameter. It can be concluded therefore that at the current stage of development, the plasma ISV process would probably not represent a significant cost saving over conventional 'top-down' ISV which costs between \$350 and \$750 per ton of soil depending on size.

The costs for competing closure technologies such as installing a RCRA type cover or in-situ stabilization have been obtained from both internal and external published sources^{3,4} and show costs about half that of vitrification. However the projected longevity of these closure systems is considerably less than vitrification but still within the range required by the majority of waste units in the SRS CERCLA program where only short half life radionuclides such as Cs-137 and Sr-90 are typically the risk drivers.

7.0 CONCLUSIONS AND RECOMMENDATIONS

The demonstration was considered to have achieved the following successes:

- Use of plasma torch technology for 'bottom up' ISV of SRS soils was demonstrated to be a practical process on a production scale.
- The process was proven to be inherently safe as no rapid steam or gas expulsion event occurred during the demonstration. In fact, for a period of time during most runs, the torch leaked water from the failed front o-ring into the cavity and onto the molten glass with no obvious deleterious effect.
- Glass samples showed complete vitrification with little porosity and possessed a very high resistance to leaching.
- Essential engineering data necessary for cost comparison and engineering development of a full scale process system was obtained, and is presented in the Appendices of this report.
- Capture efficiency of relatively volatile contaminants such as Cs by the glass was high and observed particulate emissions were low.

The following are lessons learned from the demonstration that should be addressed during any further development of the process:

- From visual observation, the principal operating parameters that affects glass column development is the torch withdrawal rate and the height of the torch nozzle above the melt. During run #1, the nozzle was maintained at about 30 in above the melt and produced a fairly narrow column. During runs #2 and #3, the torch nozzle was maintained at 24 in and 18 in respectively above the melt and produced successively wider columns. This emphasizes the need for development of a practical control system for reliably maintaining this distance during remote operation.
- The reliability of critical torch components was unacceptable for consideration in any full scale radioactive operation. The life of the front electrode and front o-ring must be improved significantly as well as redesign of the torch for vertical operation.
- Non intrusive methods for post installation QA of the finished subsurface monolith need to be proven, where the resolution would be adequate to convince regulatory agencies that a consistent product quality had been achieved in order to gain approval for a final closure action.

8.0 LIST OF REFERENCES

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9.0 LIST OF APPENDICES

- A. Technical Task Plan for the Demonstration of Plasma In-situ Vitrification at the K-Reactor Seepage Basin, WSRC-RP-96-00834, Revision 1, October 1996..
- B. Product Consistency Test (PCT) results on glass leachability.
- C. Contaminant mass balance between glass and offgas.
- E. Geophysical survey data for non-intrusive monitoring.
- E. Melt level determination by Time Domain Reflectometry and ultrasonic depth measurement.
- F. Torch operating parameters
- G. Photographs.

Plasma torch and support frame in operation.
Power supply, control room and water cooling system trailers.
Vitrified monolith from run #3.

APPENDIX A

Technical Task Plan for the Demonstration of plasma In-situ Vitrification at the K-Reactor Seepage Basin

WSRC-RP-96-0034, Rev. 1, October 1996

TECHNICAL TASK PLAN

FOR THE

DEMONSTRATION OF PLASMA IN-SITU VITRIFICATION AT THE K-REACTOR SEEPAGE BASIN

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LIST OF ABBREVEATIONS

AC	Alternating Current
BSRI	Bechtel Savannah River Incorporated
°C	Degrees Celsius
CPT	Cone Penetrometer Test
DC	Direct Current
ERD	Environmental Restoration Department
ft.	Feet
HVAC	Heating Ventilating and Air Conditioning
ins.	Inches
kW	Kilo Watts
lb.	Pounds
ISV	In-Situ Vitrification
mW	Mega Watts
PCT	Product Consistency Test
PPE	Personal Protective Equipment
QA	Quality Assurance
SRS	Savannah River Site
SRTC	Savannah River Technology Center
WSRC	Westinghouse Savannah River Company

TECHNICAL TASK PLAN

DEMONSTRATION OF PLASMA IN-SITU VITRIFICATION AT THE K-REACTOR SEEPAGE BASIN (U)

1.0 Introduction

11x30
300
400
The In-Situ Vitrification (ISV) process potentially offers the most stable waste-form for containment of radiologically contaminated soils in SRS waste units, while minimizing personnel exposure during the remediation. An earlier ISV process utilized joule heating of the soil to generate the subsurface molten glass product. However previous test work has indicated that SRS soils may not be entirely suitable for vitrification by joule heating due to their highly refractory nature. The concept of utilizing a plasma torch for soil remediation by in-situ vitrification has recently been developed, and laboratory test work on a 100 kW unit has indicated a potentially successful application with SRS soils. The Environmental Restoration Department (ERD) intends to demonstrate this technology in the field starting in October 1996.

This demonstration will take place in 2 phases. Phase 1 will take place during October 1996 at a clean location adjacent to the K-Reactor Seepage Basin. Phase 1 will test the process at a production scale, and will prove the torch operating parameters and control methodology that will be deployed for radioactive operations; together with post installation QA monitoring methods and product quality. If phase 1 is successful, then phase 2 will be conducted in late 1997 at a suitable radiologically contaminated waste unit. This task plan describes the field activities taking place during the phase 1 demonstration only. The demonstration site is shown in Figure 1 and will be located in the area to the south of the 904-65G seepage basin, to the west of the K-Area perimeter road and to the north of the outfall from the 717-65K building.

2.0 Process Description

A plasma torch operates by striking a DC electric arc in a flowing gas stream, this ionizes the gas molecules to produce a plasma. Very high energy levels can be generated within a small flame volume, which makes the process ideal for inserting down a borehole to vitrify contaminated subsurface soils. Plasma torches have been developed over the last 40 years and have reached reliable power levels of up to 10 MW. This demonstration at SRS is the first known field application of plasma technology to waste site remediation.

A non-transferred arc plasma torch generally consists of a cylindrical water cooled steel barrel, with two electrodes at the tip. Internal electrical connections are provided to the electrodes and a small volume of gas, in this case air, is passed down through the barrel. The electric arc passes between the electrodes which raises the air temperature to between 5,000 and 10,000 °C. The flowing air carries the plasma flame beyond the torch tip to produce a flame about 18 ins long. The torch barrel consists of several concentric stainless steel tubes which allow the passage of cooling water to the tip electrodes. The water passages also carry the electric current to the tip electrodes which are electrically insulated by internal separators and o-rings. Electrode erosion from the arc is controlled by automatically cycling the air flow rate. The torch system to be used in this demonstration (shown in Figure 2) has been manufactured by Plasma Energy Corp. of Raleigh, NC and is being leased for the demonstration from Hydro-Quebec of Montreal, Canada. Other components of the plasma torch system consist of a power supply and control panel which converts site grid AC power to DC, with a recirculating water cooling system to extend hot zone component life. The 1.0 MW torch is fully portable, it is supplied with all ancillary equipment on two road trailers, and only requires 4160V 3 phase AC electrical power.

The field process operates by first boring or punching an 8 in diameter hole from the ground surface down to a level just beyond the waste layer. The torch is inserted down to the bottom of the hole and energized. As the soil melts, it forms a roughly spherical cavity, the lower half of which fills with molten glass, and the upper half serves as the space for the plasma flame. The torch is slowly withdrawn out of the hole to create a column of glass which extends up through the waste layer. A large waste area is vitrified by relocating and re-inserting the torch to create multiple vitrified columns on a spacing which allows the glass 'bulbs' to join at their extremities to create a continuously vitrified monolith.

3.0 Objectives of the Demonstration

The objectives of the demonstration are to test out the Plasma ISV concept using a 1.0 mW production scale torch system and establish the torch operating and control parameters in preparation for the subsequent phase 2 hot demonstration. In addition the post installation QA methods for determining consistency of the subsurface monolith and its resistance to chemical leaching shall be determined. Specific objectives of the phase 1 demonstration are as follows:

- To demonstrate that the in-situ vitrification of soil using a non-transferred arc Plasma torch is a practical industrial process for the remediation of a radioactive waste site.
- To establish the principal torch operating parameters i.e. power level, withdrawal rate control, etc. to produce a vitrified monolith of optimal and controllable dimensions and quality.
- To produce several vitrified bulbs in close proximity to each other, such that complete coalescence into a single vitrified monolith can be achieved.
- To determine gaseous emission rates of Criteria and listed Hazardous Air Pollutants (principally PM₁₀, NO_x and heavy metals) from the process such that the offgas collection system for the future radioactive phase 2 demonstration can be designed and permitted.
- To verify that the vitrified in-situ product passes all applicable regulatory leachability and quality tests.
- To demonstrate that conventional non-intrusive geophysical subsurface monitoring techniques can be adapted for monitoring ongoing process quality control during the in-situ vitrification installation, for post installation performance verification quality assurance and also to assist in obtaining regulatory approval for closure actions using this technology.

Specific methodologies of the phase 1 demonstration are as follows:

3.1 Pre-demonstration site characterization

Prior to the actual demonstration, three torch boreholes will be made. Soil characterization will be accomplished with a combination of Shelby Tube, Split Spoon and CPT samples to the pattern indicated in Figure 3. At the same time a thermocouple matrix will be installed for monitoring the geometry of the first bulb by temperature measurement. Both physical properties and the chemical analyses of the soil shall be made. The physical properties shall include moisture, loss on ignition, particle size and x-ray diffraction of the crystalline phases. The chemical analysis shall include the soluble-insoluble fractions, carbon analysis chemical analysis and redox ratio.

3.2 Demonstrate torch withdrawal control scheme

During the radioactive phase 2 of the demonstration, the torch withdrawal rate will have to be controlled remotely. Therefore a system for monitoring the melt level will be tested during the phase 1 cold demonstration. Possibly more than one melt level monitoring system may be tried while the torch is operating, and data will be verified by manually probing the melt level down through the borehole.

The diameter of the vitrified soil column determines the spacing of the hole pattern for multiple torch insertions for creating a continuous vitrified layer. Laboratory testing on SRS soils using 100 and 200 kW torches produced columns of 17 and 22 ins in diameter respectively. The bulb diameter produced by a 1.0 mW torch is unknown but thought to be in the 3 to 4 ft. diameter range. The bulb diameter is also a function of torch withdrawal rate; too slow and the molten material will reach the torch nozzle; too fast and the bulb diameter will be too narrow. The first three tests will be designed to optimize the bulb diameter/ withdrawal rate relationship for the specific soils at the K-Area Seepage Basin.

Three 8 in. diameter holes will be bored or punched to a depth of 6 ft. on approximately a 10 ft. spacing. Each hole will be lined with 8 in. diameter non-galvanized steel HVAC ducting or thin wall carbon steel pipe to form a sleeve which prevents collapse of the sidewalls. The torch will be inserted until the nozzle tip is at a depth of approximately 48 ins or at a measured depth below a reference mark indicating ground level.

The torch will be energized, ramped up to approximately a 1.0 mW power level, then slowly withdrawn over a period of about 8 hours, or until the roof of the cavity is within approximately 6 ins. of the ground surface. The torch does not have to be withdrawn continuously but can be raised incrementally. During torch start up, the level of molten glass will rise more rapidly than after the full cavity has formed. The projected rate of rise for the initial start up period is in the 36 in/hr range which should fall progressively to about 9 in/hr after the cavity is fully formed.

After start up, the molten pool level will be determined with the control system then manually probed with a stainless steel rod, and recorded every 20 minutes. When the rate of rise and the thermocouple array has indicated that the cavity is fully formed, the level will be determined and probed approximately every hour, or as necessary. At all times when the melt level is being manually probed, power to the torch will be cut off and locked out. As the optimum rate of withdrawal is unknown, the first three tests will be used to determine this rate, using average withdrawal rates in each of the three boreholes of 18 in/hr, 12 in/hr and 6 in/hr.

The vitrified bulbs cannot be exhumed until the glass has had time to cool down to a reasonable temperature, which may take a week or more. In the meantime the bulb subsurface configurations will be determined by non intrusive geophysical methods (see section 3.4) and verified by probing with a steel rod. The location of the cavity roof will also be determined by non intrusive methods and by probing with a stainless steel rod. From these tests, the spacing for vitrification by multiple bulbs over a larger area will be determined as described in section 3.3 .

3.3 Make a continuously vitrified monolith from several bulbs

Three or four holes will be bored on a spacing determined from section 3.2 above in a staggered pattern. Again each hole will be 8 ins. in diameter, bored or punched to a depth of 6 ft and lined with 8 in diameter non-galvanized steel HVAC ducting or thin wall carbon steel pipe.

One of the columns from the previous test in section 3.2 can be used as one of the glass bulbs in this test. A series of glass bulbs will be created using the optimum torch withdrawal rate as determined from section 3.2 above. Again after the bulbs have been created, non-intrusive methods will be used to verify bulb continuity and after sufficient time has passed for the glass to cool, the monolith will be excavated and tested as described in section 3.5.

3.4 Demonstrate non-intrusive monitoring methods

Non-intrusive testing will be applied to the site prior to the demonstration to establish baseline conditions for the soil. Between two of the first three tests, and based on the results of the baseline investigation, one or two of the most appropriate geophysical techniques will be selected to determine the subsurface geometry of the subsurface bulb. This test will be used to establish the suitability of geophysical techniques for ongoing process control during installation. The same methods that were deployed during the baseline investigation will be applied after the demonstration to assess the change in geophysical properties at the site and the changes produced by ISV. This test will establish the suitability of geophysical methods for post installation monitoring. The following methods will be tried during the demonstration for verification of the subsurface monolith:

- Soil temperature measurement (see Figure 4)
- Cross hole seismic surveying
- Ground Penetrating Radar (GPR)
- Surface resistivity surveys
- Electromagnetic surveys
- Magnetometer surveys

The ultimate objective is to establish one, or a combination of methods that can be deployed during the phase 2 hot demonstration that will verify the areal extent, depth and physical consistency of the subsurface product, without recourse to physical excavation.

3.5 Product quality

After both the single and multiple monolith formations have cooled down, the soils surrounding the monoliths will be removed by backhoe and loose soil will be removed by water spray or equivalent, and the multiple monolith structure will be examined visually for continuity of the vitrification process. Physical samples will also be taken and tested for chemical leachability.

Physical samples will be taken from all monoliths and tested for physical properties and chemical analyses. The physical properties will include crush strength of the glass, density and x-ray diffraction of any crystalline material. The chemical analysis will include the redox ratio, chemical analysis and Product Consistency Test (PCT).

3.6 Offgas Monitoring

During the second and third runs, Clemson University will monitor the offgas exiting the borehole for airborne emissions. Each offgas measurement run will last for one hour during which the torch must be operated continuously and close to the optimal power level.

The offgas measurement runs will take place during the interval between torch elevation changes and will occur towards the end of a run when the cavity is fully formed.

EPA Method 7C described in 40 CFR Part 60 will be used to determine the emission rate of NO_x and EPA Method 29 will be used to determine the emission rates of SCDHEC Standard 8 listed Hazardous Air Pollutants together with PM10 and water. The samples will be taken by inserting a quartz probe into the exit gap of the borehole between the torch barrel and the steel jacket. The sample gas will be transmitted to the sample trains by a flexible hose which will be located outside of the Exclusion Area. The sample rate will not be determined isokinetically but will be proportioned from the measured rate of air flow into the torch.

4.0 Sequence of Events during the Demonstration

The sequence of events during the demonstration and the approximate time schedule is outlined as follows:

September - Site preparation including:

- install transformer, transformer pad, hook up to site grid, circuit breaker
- place gravel road bed, mow grass, locate trailer
- drill and line 3 boreholes
- characterize site and install instrumentation
- run baseline geophysical site characterization tests
- fabricate torch gantry and platform

October - Conduct demonstration including:

- assemble equipment and connect to transformer
- check out torch power and control systems and test fire the torch outside of a borehole
- run initial 3 tests to determine bulb diameter/torch withdrawal rate relationship
- drill and line 3 boreholes for multiple bulb test
- run limited geophysical monitoring methods over completed bulbs
- run multiple bulb test
- disassemble torch equipment and return to Hydro-Quebec

November - Post test characterization including:

- repeat baseline geophysical techniques to determine subsurface melt geometry and continuity
- after subsurface melts have cooled, remove loose soil from around multiple bulbs and visually assess quality and continuity
- remove glass samples from each bulb and test for product quality
- backfill site

5.0 Safety Plan

The complete Safety Plan for the Plasma In-situ Vitrification Demonstration is given in Appendix A, however the main features of the plan are as follows.

5.1 Demonstration and Exclusion Zones

While the subsurface vitrification process is taking place, and for some time after the process is complete, there will be a subsurface cavity which will be half filled with molten glass. This cavity could be up to 5 ft. in diameter, with a brittle crust comprising the roof and will be just below the ground surface. The ground above the cavity will collapse if subjected to any weight at all, therefore all personnel will be absolutely prohibited from approaching the vicinity of the subsurface vitrification, unless authorized by the Demonstration Field Manager. An Exclusion Zone will be cordoned off around the boreholes as shown in Figure 3, with entry permission strictly controlled and authorized only by the Demonstration Field Manager or his assigned designee.

At times during the demonstration, one or two personnel will be required to approach the torch and the borehole for the purposes of making adjustments or relocating the torch. A platform/torch support frame will be provided over the area that may be subject to subsidence, and personnel within the Exclusion Zone must not step foot off this platform at any time. All rigging adjustments for torch manipulation together with geophysical, offgas and temperature monitoring must be carried out from the platform. Any movement of the platform and the Exclusion Area barrier can only be made under the supervision of the Demonstration Field Manager.

With any high temperature process where molten materials can come into contact with moisture, the potential is always present for the accumulation of a subsurface pocket of steam. The plasma ISV process is designed to vent any subsurface gases to the atmosphere through the open borehole, thus minimizing any pressure build up which could result in either a sudden disturbance or eruption in the molten pool, or sudden steam venting to the atmosphere through the surrounding soil. Therefore as a safety precaution, to minimize the hazard should this event actually occur, an outer Demonstration Zone will be cordoned off around the entire area where the demonstration is being conducted.

While the torch is operating, permission to enter the Demonstration Zone by named personnel can only be obtained in advance from the Demonstration Field Manager. While the torch is operating, the number of personnel permitted to enter the Demonstration Zone will be strictly limited to those personnel essential to operate the torch, the torch electrical systems and monitoring equipment. During periods when the torch is not operating, the people permitted to enter the Demonstration Zone will be kept to an absolute minimum and will be at the discretion of the Demonstration Field Manager. This Demonstration Zone will encompass all the boreholes, monitoring locations as well as the Exclusion Zone, plasma torch support equipment, trailers and electrical transformer and distribution equipment. Personnel entering both the outer Demonstration Area and inner Exclusion Zones at any time, will sign in and out on a log-sheet with the date and time.

Before each actual demonstration run, a briefing will be given by either the Demonstration Field Manager, the ER Engineering lead or SRTC lead to all personnel scheduled to enter the Demonstration Zone during the expected duration of the run. The briefing agenda will cover the expected sequence of activities during the run, who will be responsible for which specific activity, any anticipated hazards with procedures to be followed and required PPE.

5.2 Demonstration Fugitive Emissions

The selected site location is free of contamination, therefore precautions concerning contact with radioactive or hazardous waste contamination are not required.

However due to the extremely high temperatures generated by the plasma torch, some volatilization of materials in the soil will occur. These emissions will consist of particulates, which will be mainly volatilized silica together with minor background trace metal oxides and gases present in the soil. These emissions will emanate from the borehole while the torch is running. Therefore WSRC Industrial Hygiene coverage will be required, for at least the initial portion of the test program, to assess emission levels and determine the appropriate level of respiratory protection required for the demonstration team members.

5.3 Demonstration Field Manager

All activities within the Demonstration Zone will be the responsibility of the Field Demonstration Manager, (Mr. P. G. Zionkowski 803 952-6487, Pager 5758). This includes activities by all subcontractor personnel, technical consultants, WSRC Industrial Hygiene, BSRI Construction and all ERD and SRTC personnel. The Demonstration Field Manager will be responsible for all aspects of safety concerning the demonstration and will have the authority to terminate activities which are judged not to be in compliance with SRS safety manuals and procedures.

6.0 Quality Assurance

Responsibilities for the various aspects of this demonstration are divided among several organizations as follows.

ERD Demonstration Field Manager - Responsible for all activities within the Demonstration Zone.

ERD Engineering - Design authority responsible for all engineering activities associated with the demonstration including making engineering calculations for environmental permitting. Also providing support to the Demonstration Field Manager for torch operation.

ERD Environmental Compliance - Responsible for obtaining all environmental permits from regulatory authorities.

Hydro-Quebec - Responsible for providing 1 mW portable plasma torch and associated equipment. Also responsible for ensuring satisfactory operation of the torch and associated equipment during the demonstration. Will provide services of technical specialist to supervise the assembly, testing, initial operation of the torch and instructing WSRC or BSRI operators on torch operation.

WSRC Power Department - Responsible for providing 1.0 mW of electrical power at 4160 Volt, 3 phase AC to the torch power supply for the duration of the demonstration.

WSRC Industrial Hygiene - Responsible for determining personnel exposure to particulates during periods when the torch is operating and setting PPE requirements.

BSRI Construction - Assembly and disassembly of torch equipment together with some torch operation activities during the demonstration.

Savannah River Technology Center - Responsible for interface with Georgia Institute of Technology, Clemson University and assessment of wasteform quality.

Georgia Institute of Technology - Responsible for originating Plasma ISV concept, design of the melt zone instrumentation for the demonstration including melt level detection and torch withdrawal rate control. Also responsible for some initial site characterization and non-invasive monitoring of the waste form size location and integrity.

Clemson University - Responsible for monitoring process offgas for regulated air pollutant emissions.

Demonstration responsibilities for field operations within the Demonstration Zone:

ERD Field Manager

7.0 List of Figures

- Figure 1, K-Area Site Map.
- Figure 2, Diagram of Non-Transferred Arc Plasma Torch.
- Figure 3, In Situ Plasma Vitrification Technology Demonstration Test Site Area Layout
- Figure 4, Layout of thermocouple array.

8.0 List of Attachments

- Attachment A - Safety & Health/Accident Prevention Plan (U) for the Demonstration of Plasma In-Situ Vitrification at the K-Reactor Seepage Basin (904-65G), September, 1996.

NON-TRANSFERRED TORCH

TORCH MODEL NO: PT250N602

TORCH SERIAL NO: PT250N6020602III7

ALL DIMENSIONS IN INCHES.

GI SHROUD GROUNDING: 500 MCM LUG FLAT WITH $\frac{5}{8}$ "-UNC TAPPED HOLE

XI INPUT WATER-POWER (-) CONNECTION: MALE $1\frac{1}{2}$ " NPT

X2 INPUT PLASMA GAS CONNECTION: MALE $\frac{3}{4}$ " NPT (PIPE OD: .050")

X3 OUTPUT WATER-POWER (-) CONNECTION: MALE $1\frac{1}{2}$ " NPT (PIPE OD: .1900")

DRY WEIGHT (LBS):

WET WEIGHT (LBS):

DWG NO. PT250N-0000-402

Counter pole

Pole

Fenced

TEST AREA

- A. Vertical Thermocouple array
- B. Cone penetrometer test
- C. Vertical Thermocouple array
- D. Secondary Bore hole 75mm
- E. Secondary Bore hole 100 mm
- F. Piezometer for pressure monitoring
 - 1. Primary bore hole
 - 2. Primary bore hole
 - 3. Primary bore hole
 - 4. Primary bore hole
 - 1a. Secondary bore hole
 - 2a. Secondary bore hole
 - 3a. Secondary bore hole

In Situ Plasma Vitrification Technology Demonstration Test Site Area Layout

Figure 3.

APPENDIX B

Product Consistency Test (PCT)

data on glass leachability

WESTINGHOUSE SAVANNAH RIVER COMPANY
INTER-OFFICE MEMORANDUM

To: Robert F. Blundy - ERE cc: D.A. Crowley - 773-43A
D. Herman - 773-41A
From: Ray F. Schumacher - SRTC-VTS C. Cicero-Herman - 773-43A
D.F. Bickford -773-43A
Date: August 11, 1997 SRTGFM-97-051
Subject: PCT Results - K Reactor Demonstration

Introduction

During November of 1996, a demonstration of In-Situ Plasma Vitrification was conducted adjacent to the K-Reactor Seepage Basin (904-65G). A brief discussion of the planned experiment, observations and conclusions was issued at the end of 1996 [1]. The present report will describe some of the observations on K-Reactor soil, the reclaimed monoliths, and durability testing of the glass in the monoliths. The glass was found, as expected, to have a resistance to leaching in water several orders of magnitude better than the Environmental Assessment glass for high level waste.

Monoliths

Measurements of the three monoliths were made and are reported in the attached drawings as Melts No. 1, 2 and 3. Melt No.1 was produced on Nov.7, 1996 and resulted in a small cone shaped monolith which weighed approximately 600 lbs. Melt No. 2 was made on Nov. 9, 1996, had a maximum melt diameter of 3.5 ft., and a weight of 1100 lbs. Melt No. 3 was completed on Nov.12, 1996, had a maximum diameter of only 2.5 ft., but weighed 1250 lbs. With increasing melt number, the power to the torch and times of operation were increased.

Seepage Basin Soil Composition

A sample of the K-Reactor soil was submitted to ADS for chemical analysis (NB#9383-9, sample 20). A sample of vitrified soil from the second melt run was submitted as NB#9383-11, sample 1. The chemical analyses did not sum to 95-100% so the analyses were normalized to 100%. The results are presented in Table 1 and compared to values from the literature. The SRS soils are sands with an addition of calay. The SiO₂ levels tend to be in the vicinity of 90%.

Table 1, Normalized Chemical Composition-Vitrified K-Reactor Soil/Glass

Oxide	Soil 9383-9-20 Wt%	Glass 9383-11-1 Wt%	Typical[3] SRS Soil Wt%
Al ₂ O ₃	2.41	4.13	4.80
CaO	0.06	0.16	0.40
Cr ₂ O ₃		0.14	
Fe ₂ O ₃	0.75	3.33	0.7
K ₂ O			0.13
MgO	0.01	0.10	
MnO	0.38	0.02	0.01
Na ₂ O			0.05
NiO		0.11	
P ₂ O ₅		0.09	1.12
SiO ₂	95.69	91.27	92.50
SrO	0.08	0.01	0.001
TiO ₂	0.42	0.53	0.40
ZnO	0.03	0.03	0.05
ZrO ₂			0.09

Redox Ratio

The redox ratio, ferrous iron/total iron, was determined along with a standard sample of the Environmental Assessment (EA) glass. The redox ratio for sample 9383-11-1 (Melt No.2) was determined to be 0.84 and the EA glass was 0.21. The average redox ratio for the EA glass was determined to be 0.22 [4]. This ratio indicates that the glass is well reduced with eight of ten iron atoms in the +2 valence state. This is probably the result of the carbon content of the soil and the extremely high temperature of the plasma flame.

Glass Durability

A "Product Consistency Test" (PCT) was carried out on a sample of the second moolith(NB9383-11-1). The PCT is used to measure the consistency of the high level waste glasses from the Defense Waste Processing Facility. The test normally determines the amount of alkali or boron in the leachate after a seven day immersion test. Because there is little or no alkali or boron in the SRS soil, the amount of silicon was used to determine the dissolution of the glass.

The test was carried out in triplicate per the standard PCT evaluation procedure [5]. Standards and blanks were employed, but no corrections were made to the analytic results. The leachate determinations are presented in Table 2. The normalized release for the glass was calculated by dividing the adjusted leachate concentration in ppm by the elemental fraction of the element in the glass.

Table 2, Normalized Release PCT results - Sample NB 9383-11-1

Element-i	Release-i (ppm)	Fraction-i	Norm. Release-i (gm glass/liter leachate)
Al	0.133	0.041	0.003
Ca	0.206	0.0016	0.129
Mg	0.043	0.001	0.043
Mn	0.022	0.0002	0.111
P	0.040	0.0009	0.044
Si	8.718	0.9127	0.010
Zn	0.143	0.0003	0.476

The normalized release of silicon from the glass into the leachate was 0.010 gm glass/ liter leachate. This is several orders of magnitude better than the 3.9 to 4.2 g/l obtained for the DWPF Environmental Assessment (EA) glass. The PCT test was established for glasses similar to the DWPF glass and these glasses contain alkali and boron. In these glasses silicon is also tracked as a measure of dissolution of the matrix itself; however, it is known that back-precipitation reactions can occur during the test period which could slightly under-represent the amount of matrix dissolution. Since boron and alkali are not present in the SRS soil to any appreciable amount this is probably as good a value as is available. It is also known widely throughout the literature that very high silica glasses are quite durable and these results support this.

References

1. "Technical Task Plan for the Demonstration of Plasma In-Situ Vitrification at the K-Reactor Seepage Basin," WSRC-RP-96-00834, Rev.0, Sept 6, 1996.
2. R.F. Blundy, P. Zionkowski, R.F. Schumacher, and D.T. Herman, "Demonstration of Plasma In-Situ Vitrification at the K-Reactor Seepage Basin (904-65G),"
3. C.A. Cicero, et.al. "Vitrification of Savannah River Site Contaminated Soils," I&EC Special Symposium, ACS, Atlanta, GA, September 17-20, 1995. Pub. ACS, Washington, DC, pg.616-618
4. C.M. Jantzen, et.al. "Characterization of the DWPF Environmental Assessment Glass Standard Reference Material," WSRC-TR-92-346. June 1, 1993.
5. C.M. Jantzen, et.al. "Nuclear Waste Glass Product Consistency Test (PCT) - Version 7.0 (U)," WSRC-TR-90-539, Rev.3 June 1994.

MELT NO. 1

$$\begin{aligned} \text{Cone} &= \frac{1}{3} \pi r^2 h \\ \text{Vol} &= \frac{1}{3} \times \pi \times 1 \times 3 \\ \text{Vol} &= 3.1 \text{ cu ft.} \\ \text{Wt.} &= 3.1 \times 62.4 \times 2.2 \\ \text{Wt} &= 430 \text{ lb.} \end{aligned}$$

Actual Wt = 600 lb

MELT NO. 2

2' - 3"

$$\begin{aligned} \text{Vol} &= \pi [(r_1 + r_2)/2]^2 h \\ \text{Vol} &= 6.1 \text{ cu ft} \\ \text{Wt.} &= 840 \text{ lb} \end{aligned}$$

$$\begin{aligned} \text{Vol} &= \pi [(r_1 + r_2)/2]^2 h \\ \text{Vol} &= 4.5 \text{ cu ft} \\ \text{Wt} &= 620 \text{ lbs} \end{aligned}$$

$$\begin{aligned} \text{Vol} &= \pi [(r_1 + r_2)/2]^2 h \\ \text{Vol} &= 3.0 \text{ cu ft} \\ \text{Wt} &= 410 \text{ lbs} \end{aligned}$$

$$\begin{aligned} \text{Vol} &= \pi r^2 h \\ \text{Vol} &= 0.25 \text{ cu ft} \\ \text{Wt} &= 34 \text{ lb} \end{aligned}$$

$$\text{Total} = 840 + 620 + 410 + 34 = \sim 1900 \text{ lbs}$$

Actual Wt = 1100 lb.

MELT NO 3

$$\begin{aligned} \text{Vol} &= \pi r^2 h \\ \text{Vol} &= \pi 1.25^2 1.0 \\ \text{Vol} &= 4.9 \text{ cu ft} \\ \text{Wt} &= 675 \text{ lbs} \end{aligned}$$

$$\begin{aligned} \text{Vol} &= \frac{4}{6} \pi r^3 \\ \text{Vol} &= 4.1 \text{ cu ft} \\ \text{Wt} &= 565 \text{ lbs} \end{aligned}$$

$$\begin{aligned} \text{Vol} &= \pi r^2 h \\ \text{Vol} &= .65 \text{ cu ft} \\ \text{Wt} &= 90 \text{ lbs} \end{aligned}$$

$$\text{Total} = 675 + 565 + 90 = 1330 \text{ lbs}$$

APPENDIX C

Contaminant mass balance between the glass and offgas

Calculation of contaminant mass balance between the glass and offgas

From the offgas test run soil data (see attached e-mail message of 11/24/97), 84 lb of SRS soil was vitrified in 80 minutes. The soil was doped with 9.8 ppm of Cs⁺ and 9.9 ppm of Sr⁺⁺ non radioactive simulants. Assuming that the Cs and Sr remained evenly distributed as the soil was vitrified, then the quantities of these contaminants that were vitrified, when averaged over 60 minutes, is:

$$84 * 454 * 9.8 * 60 / 84 * 10^6 = 0.267 \text{ grams of Cs}$$

$$84 * 454 * 9.9 * 60 / 84 * 10^6 = 0.2696 \text{ grams of Sr}$$

The offgas was sampled for 60 minutes and the test data (see attached FAX of 11/05/97) showed that (6.7 + 0.01) µgrams of Cs, along with 0.1 µgrams of Sr were collected in the Method 29 sample train. The quantities of these contaminants that were passing into the atmosphere via the offgas vent on the GIT test rig in 60 minutes was therefore:

$$(6.7 + 0.01) * 1.15 * 60 / 1.404 = 329.76 \text{ µgrams of Cs}$$

$$0.1 * 1.15 * 60 / 1.404 = 4.914 \text{ µgrams of Sr}$$

$$147.95 * 1.15 * 60 = 10208.55 \text{ mgrams of total particulate matter}$$

The proportion of the vitrified material that was volatilized was therefore:

$$100 * 329.76 / (0.267 * 10^6) = 0.1235 \% \text{ of Cs}$$

$$100 * 4.914 / (0.2696 * 10^6) = 0.0018 \% \text{ of Sr}$$

$$100 * 10.208 / (84 * 454) = 0.0268 \% \text{ as particulates}$$

Assuming that there was no migration of Cs and Sr from the hot to the cold areas of the soil within the test container, the capture efficiency of the vitrification process was therefore (100 – percent volatilized) or 99.8765 % for Cs and 99.9982 % for Sr.

R.F.B. 12/17/97

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 TO: robert.blundy at Mailhub
 CC: newsome@eoeml.gatech.edu at Mailhub
 Subject: Plasma Experiment w/ Off Gas
 Bob,

I believe this is the information you need. In the experiment there was a contaminated core of soil with a 9.75 inch radius. This soil was surrounded by clean soil to fill the 12 inch radius container. I believe I faxed you a diagram of this design in February. If you need a picture again I can send it to you. The soil information is displayed below:

Table 1. Initial Conditions of Test Set Up

	Contaminated Soil	Clean Used Soil
Volume of soil (ft ³)	5.0	4.0
Total Mass of Soil (lbs)	556	456
Total Density (pcf)	111	114
Moisture Content (%)	11.3	11.5
Dry Density (pcf)	100	102
Mass CsCl (g)	3.13	0
Concentration as Cs+ (ppm)	9.8	0
Mass of Sr(NO ₃) ₂ (g)	6.04	0
Concentration as Sr(2+) (ppm)	9.9	0

Table 2. Torch Position Data

Cumulative Time (min)	Increment (min)	Torch Raised (inches)	Total Length (inches)
10	10	3	3
21	11	3	6
31	10	2	8
45	14	2	10
60	15	3	13
30	20	Torch Off	13

Table 3. Melt Mass

Final Mass (lbm)	Average Power (kW)	Duration (hr)	Power Consumption (kW-hr)
84	96	1.33	128

If you need anything else feel free to contact me.

James Schneider
 gtd442a@prism.gatech.edu
 404-894-0775

Allen Bob Blundy
Iron Dave Herman

2 pages

Post-It* Fax Note 7671

To	From	Date	# of pages
David Herman	JOHN HARMEN		2
Co./dept.	Co.		
Phone #	Phone #		
Fax # 803 725-4553	Fax #		

Concentration Calculations for Multiple Metals Analysis:
Descriptor: Georgia Tech plasma torch
Melter:

Run Date 8-Feb-97
Run Number 1

Feed rate (avg during sampling)	(none)	
Initial Gas Meter Reading:	128.243	
Final Gas Meter Reading:	143.46	
Gas Volume at meter (cu.feet):	15.217	
Non-condensable gas sampled	29.573 cu. ft.	0.837 cu. meters
	2.253 lbs. dry air	
Weight of Condensate (g):	221.81	0.49 lbs. water
Stack Temperature (deg. F):	550	
(deg K):	561	
Temp at Meter (deg. F):	60	
(deg. K):	289	
Water vapor volume sampled	0.567 cu. meter	(V=nRT @ 1atm)
Gas volume sampled at stack	1.404 cu. meter	
Gas density at sampling point	0.055 lbs/cu.ft.	
Water content of Off-gas	40% by volume	
Avg. Pitot reading at sampling pt.	0.01 in. H2O	
Stack gas flow at sampling point	41 cfm	1.15 cu.meters/min
Particulate Weight on Filter (mg)	204.7	
Particulate Weight in Rinse (mg)	3 (est)	
Particulate Conc.	147.95 mg/cu meter	

Metal of Interest	From front (ug)	From tail-end (ug)	Conc. in Off-gas (ug/cu.meter)
Aluminum	120.7	21.5	101
Antimony	5.1	0.25	4
Arsenic	210.7	0	150
Barium	0.2	0.25	0
Beryllium	1.2	0	1
Boron	24.5	342.3	261
Cadmium	1.4	0	1
Calcium	42.7	22.9	47
Cesium	6.7	0.01	5
Chromium	378.4	2.6	271
Cobalt	1.1	0.05	1
Copper	11344	0.4	8081
Iron	10129	10.2	7222
Lead	194.7	0	139
Magnesium	8.1	7.2	11
Manganese	11	0.6	8
Molybdenum	31.6	0.06	23
Nickel	15.1	0.5	11
Potassium	109.8	7.2	83
Selenium	3	0	2
Silver	5	0	4
Sodium	42.7	33.6	54
Strontium	0.1	0	0
Thallium	1.9	0	1

Tin	28.3	2.6	22
Titanium	75.2	5.4	57
Uranium	10.4	0	7
Vanadium	202.3	6.2	149
Zinc	192.5	1.6	138
Mercury	39.2	18.5	41
Sum of particulate metals (ug/m3)	16551		
Sum of volatile metals (ug/m3)		345	
Sum of Metals in offgas (ug/m3)			16896

Author: johnh@CLEMSON.EDU at Mailhub

Date: 11/19/97 3:32 PM

Priority: Normal

BCC: ROBERT BLUNDY at SRCCB10

TO: robert.blundy at Mailhub

CC: derich@CLEMSON.EDU at Mailhub, david.herman at Mailhub, ray.schumacher at Mailhub, peter.zionkowski at Mailhub

Subject: Re: Data for Plasma ISV Mass Balance

Bob,

My spreadsheet is only for offgas calculations. From that spreadsheet, however, you have enough information to get the mass of material given off in the offgas. My sampler indicated a stack flow of 1.15 actual cu.meters/min at the sampling point, which was at 561 deg. K.

For example, with strontium:

$0.1 \text{ ug Sr} / 1.404 \text{ cu.meters} \times 1.15 \text{ cu. meters/min} \times 60 \text{ minutes} = 4.9 \text{ ug Sr.}$

(Not very much strontium given off!)

For total particulate matter:

$147.95 \text{ mg/cu.meter} \times 1.15 \text{ cu. meters/min} \times 60 \text{ min.} / 1000 \text{ mg/g} = 10.2 \text{ g}$
total particulate matter.

This seems a bit low, but the particulate matter was very light and fluffy.

At one time I had the concentrations of the spiked metals on E-mail messages we were sending back and forth. Unfortunately, all my old E-mail files are tied-up in some irretrievable electronic limbo since I switched to my new computer.

The GA Tech crew should have all that information, as well as the glass weight.

Good luck.

John H.

At 12:44 PM 11/19/97 -0400, robert.blundy@srs.gov wrote:

>
> John
>
> The offgas analytical data from the plasma ISV test at GT seems to be
> complete now (your FAX of 11/05097). The mass balance is still to be
> calculated and I have heard a rumor that you may have a spreadsheet
> that has done this. If so could you forward it to either myself (FAX
> 803 952-6753, robert.blundy@srs.gov) or David Herman. If the rumour
> isn't true I need the data on the concentration of Cs and Sr in the
> test soil, the weight of glass produced during the offgas run and the
> average offgas flow rate from the barrel. Do you have this
> information, part of this information or does GT have it?
>
>

> Thanks, Bob Blundy 803 952-6788.
>
>

APPENDIX D

Geophysical survey data for non-intrusive monitoring

**Summary Report
Site Characterization Program
Demonstration of Nontransferred-Arc
In-Situ Plasma Magmavication
K-Basin, Savannah River Site**

prepared by

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CEE No. E-20-M51**

March 21, 1997

Summary Report
 Site Characterization Program
 Demonstration of Nontransferred Arc
 In-Situ Plasma Magmavication
 K-Basin at Savannah River Site, S.C.

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APPENDICES

Appendix A:	Results of Standard Penetration Tests (SPT)
Appendix B:	Laboratory Grain Size, Hydrometer, and Direct Shear Test Analyses
Appendix C:	Field Data from Ground Penetrating Radar (GPR)
Appendix D:	Seismic Geophysics Data from Crosshole Testing (CHT)

EXECUTIVE SUMMARY

A field demonstration of nontransferred arc plasma magmavication of soils was completed adjacent to the K-reactor seepage basin area of the Savannah River Site in Aiken, SC, in November 1997 (see Figure 1). The very high temperatures (4000°C to 7000°C) produced by plasma technology are capable of melting all earthly materials, including soils. A 1-MW plasma torch was utilized downhole to form a single column of vitrified material and two coalesced masses (double column) in adjacent boreholes. Westinghouse Savannah River Company (WSRC) and Bechtel Corporation established and directed the field operations. Hydro-Quebec provided and operated the portable power supply, coolant systems, and plasma torches. Georgia Tech was responsible for the site characterization studies and this report documents the results of the testing of geomaterials for the project.

Several nondestructive testing techniques for site characterization were employed by Georgia Tech field crews prior to and after the in-situ magmavication program in an attempt to detect the presence, extent, and size of the resulting igneous rock products formed upon cooling of the magma. These methods included: (1) magnetics, (2) resistivity, (3) electromagnetic conductivity, (4) ground penetrating radar (GPR), (5) seismic crosshole testing (CHT), and (6) spectral analysis of surface waves (SASW). Results from these nondestructive field tests and other site characterization testing (laboratory index, direct shear, and field penetration tests) are given in this report.

The initial surveys were conducted to provide a baseline of reference values in the native slightly clayey sands. In the post-event testing, the CHT was successful in measuring the in-situ shear wave velocity profiles of both the single and double vitrified columns, while the SASW and GPR were capable of identifying only the double bulbs. The other methods encountered interference of results because of the proximity of a metal safety fence and large electrical transformer on the premises, and thus, their results are inconclusive.

TEST SITE

The test area for field plasma melting of soils was situated just south of the existing K-basin on the Savannah River Site property (Figure 2). The test site was chosen by WSRC and established as a 50-foot by 50-foot square area. At this location, uncontaminated sandy soils were known to exist and had been encountered previously during placement of some monitoring wells to approximate depths of 60 feet. The groundwater table was indicated to be about 50 feet deep at the site. The ground surface was relatively flat and grass covered.

Under subcontract to WSRC, four soil test borings were drilled by AEI to obtain benchmark data on the subsurface conditions, stratigraphy, and soil samples in the uppermost layers. The borings were advanced to depths of 8 feet deep using rotary drilling methods (augering) according to ASTM D-4700. Figure 3 shows the boring layout in the vicinity of the first (primary) burn hole that was exposed to the high temperature flame of the plasma torch.

In two of the borings, continuous drive samples were obtained using the split-barrel sampling method and standard penetration test (SPT), according to ASTM D-1586 procedures. Based on

the visual examination and subsequent laboratory testing of samples, detailed engineering logs of these borings are given in Appendix A. Neglecting a seating increment, the cumulative number of blows of the drop hammer to drive the split-barrel sampler one foot is termed the SPT-resistance, or N-value, and is used as an index as to the consistency of the soil. Penetration resistances from the two SPT borings are summarized in Figure 4. The mean value of SPT resistance was 21.5 blows per foot (bpf), with a calculated standard deviation of 7.4 bpf.

In the remaining two borings, continuous thin-walled Shelby tubes (ASTM D-1587) were hydraulically-pushed to obtain "undisturbed samples" of soils. These samples were transported to the Geosystems Laboratory at Georgia Tech and subjected to classification and strength testing. Laboratory classification testing included grain size (mechanical analyses), hydrometer analyses, and moisture contents in general accordance with ASTM standards D-422, D-2487, and 2488. The results are given in Appendix B and representative sieve analyses are presented in Figure 5.

Together with the SPT N-values, the particle size analyses indicate that the native soils at the K-basin site are composed primarily of firm slightly silty to clayey fine sands. According to the Unified Soil Classification System (USCS), the soils are primarily designated SP-SM to SP-SC. Hydrometer analyses confirm that a significant portion of the fines (particles finer than U.S. sieve No. 200, or 75 microns) are clay colloids (less than 5 microns = 0.005 mm), thus the materials may be termed "gap-graded". The lack of silt-size particles is an unusual feature characteristic of the SRS soils.

Moisture contents of retrieved specimens ranged from 9.8 to 19.1 percent by weight (ASTM D-2216), with an average of 12.4 percent. Direct shear testing was performed at three levels of confining stress (ASTM D-3080) under consolidated-drained conditions. Results given in Appendix B indicate an effective friction angle (ϕ') of approximately 32° to 34° for these sands.

NONTRANSFERRED ARC PLASMA TECHNOLOGY

The use of nontransferred arc plasma technology for in-situ magmavication of soils has been shown viable in laboratory simulation experiments (Circeo and Mayne 1993; Mayne 1994; Beaver and Mayne 1995; Mayne and Beaver 1996; Mayer 1996; Circeo et al. 1996). Soil materials have a relatively high melting point of about 1600° to 1800°C. The very high temperatures of a plasma torch (4000° to 7000°C), however, are capable of melting all material types on the planet. Chamber tests utilizing 100-kW and 240-kW plasma torches have proven effective in melting a variety of sands, silts, and clays under a range of moisture conditions and applied power levels. The resulting magma cools to form an artificial igneous rock ranging in similarity from obsidian to granite to basalt, depending upon the original soil mineralogy and the duration and rate of cooling.

The field tests conducted by WSRC are particularly noteworthy because they represent significantly higher energy levels (650 kW to 950 kW) than previously attempted, higher power consumption (up to 1740 kW-hours), and have been conducted in-situ under true field conditions. Details and initial findings have been documented in a preliminary report for the project (Blundy et al. 1996). The project utilized large 1-MW plasma torches and portable power supply and water-cooling system manufactured by the Plasma Energy Corporation (PEC).

ENVIRONMENTAL GEOPHYSICS TESTING AT K-BASIN

Series of environmental geophysical tests were performed at the K Reactor seepage basin test site before and after the plasma vitrification demonstration to evaluate their potential for detecting geomaterial changes resulting from the plasma melt. The initial characterization was performed on September 11, 12, and 26, 1996 using four different nondestructive techniques (Keary & Brooks, 1991; EPA 1993; Benson & Yuhr, 1995):

- A. Magnetic surveys;
- B. Surface resistivity;
- C. Electromagnetic conductivity;
- D. Ground penetrating radar.

For each of these surveys, a grid array of tests points was established across the site area. The approximate grid spacings were established at either 3 or 5 feet, measured center-to-center. These nondestructive tests were repeated in December 1996 after vitrification; however, a metal fence, which had been installed around the test area for safety reasons, was observed to have affected the measurements. Consequently, the team returned on January 9 and 10, 1997, after the fence was removed, and the testing was repeated. Tables 1 and 2 summarize the environmental geophysics testing programs that were accomplished for the pre- and post-melt events, respectively. Specific details on the data collected are discussed in the following sections or given in Appendix C.

Table 1. Pre-Melt Site Characterization by Environmental Geophysics Testing.

Date	Test	Comments
11 SEP 96	Magnetometer	50 x 50 grid; 3 foot spacing
11 SEP 96	Soil Resistivity	50 x 50 grid; 5 foot Wenner array
12 SEP 96	Electromagnetic Conductivity	50 x 50 grid; 3 foot spacing
26 SEP 96	Ground Penetrating Radar	Lines 0, 6, 12, and 18; NS

Table 2. Post-Melt Site Characterization by Environmental Geophysics Testing.

Date	Test	Comments
6 DEC 96	Magnetometer	18 x 18 grid; 3 foot spacing
6 DEC 96	Soil Resistivity	40 x 15 grid; 5 foot Wenner array
6 DEC 96	Electromagnetic Conductivity	18 x 18 grid; 3 foot spacing
6 DEC 96	Ground Penetrating Radar	Lines 0, 12, 15, 16, 32.5, 33.5, 34.5, 35.5, 36.5 - NS Lines 4, 7.5 - EW
9 JAN 97	Magnetometer	50 x 50 grid; 3 foot spacing
10 JAN 97	Soil Resistivity	40 x 16 grid; 2 foot Wenner array
10 JAN 97	Electromagnetic Conductivity	50 x 50 grid; 3 foot spacing

MAGNETICS

The magnetometer used in the investigation at the demonstration site was a proton precession magnetometer (EG&G Geometrics model G-856AX) which yields a measurement of the total magnetic field at a point in space and in time. Proton precession magnetometers are extremely sensitive to the magnitude of the magnetic field, but require readings at discrete points along a profile line. Magnetometers are capable of detecting magnetic metals which include iron, nickel, cobalt, and their alloys, as well as magnetic minerals (Burns and Lemons, 1996). On other sites, magnetometers have detected single 55-gallon metal drums buried up to depths of 20 ft. The measured magnetic intensity at a site varies both spatially and temporally, so it is important to account for the daily variation in the Earth's magnetic field when performing extended surveys.

The magnetometer investigations were performed on a three-foot grid spacing. The magnetometer results obtained at the K Reactor site are shown in Figures 6a and 6b. In the initial characterization survey (Figure 6a), two magnetic anomalies were detected just outside the western portion of the 50 ft x 50 ft test site. In the final site characterization (Figure 6b), one of these anomalies is still apparent in the western corner of the site. However, the presence of the large electrical transformer at the eastern corner clearly dominated the overall magnetic response and the detection of the igneous products was not possible.

SOIL RESISTIVITY

Soil resistivity meters are used to measure the apparent resistivity of subsurface materials. Resistivity is reported as apparent resistivity because the measurement is taken over a hemispherical volume with a diameter equal to that of the spacing of the outermost electrodes. The array is configured using four equally-spaced electrodes (distance a_R apart), so that the outer electrodes are a total distance of $3a_R$ from each other. Consequently, the apparent resistivity is a volume average measurement, representing bulk values of the system. Resistivity measurements are used to identify different types of subsurface materials as well as depth and thickness of soil layers, depth to bedrock, and depth to aquifers. Generally, clayey materials, which are electrically active, will have a much lower resistivity (higher conductivity) than will sandy materials, which are highly resistive (lower conductivity). The depth of penetration for the soil resistivity test is roughly equivalent to the distance spacing between the outer electrodes.

On September 11, 1996, a surface resistivity survey was conducted beside the K reactor seepage basin using an SoilTest model ELE Strata Scout R-40C soil resistivity meter on a five-foot Wenner array grid spacing (depth of current penetration of fifteen feet). Results of the initial resistivity testing indicate a highly resistive zone (sandy) on the northern side of the site (Figure 7a), parallel and adjacent to the fence which borders the seepage basin. The southern portion of the site exhibited a lower resistivity zone that is indicative of a more clayey soil.

On December 6, 1996 a post-melt resistivity survey was conducted at the site using a five-foot Wenner array grid spacing. However, the survey was conducted only along the western edge of the site due to the presence of a two-foot gravel overlay that had been placed along the eastern and southern edges of the site to provide accessibility for heavy equipment. The survey was

performed over a 30-foot by 40-foot grid (Figure 7b). High resistivities were again noted on the north side and lower values on the south.

A second post-melt resistivity survey was performed on a 15-foot by 40-foot grid on January 10, 1997. This survey again used a Wenner configuration, but with an electrode spacing of two feet rather than five feet (Figure 7c). The reduced spacing was used to try and better define the shallow igneous products formed. The prior December 6 survey had an exploration depth of approximately fifteen feet, while the January 10 survey corresponded to an exploration depth of approximately six feet.

Comparison of the pre-melt and post-melt surveys shows a higher resistivity area in the northern section of the site (parallel to the seepage basin fence) moving toward a less resistive region toward the southern end of the site both before and after the plasma demonstration. Additionally, both post-melt surveys show the same trends, indicating that soil conditions from depths of six feet to approximately fifteen feet are consistent. No strong evidence of the vitrified masses are evident from the resistivity profiles. It is also important to note that the resistivity profile of a given soil layer is strongly affected by the saturation of the soil. The surveys on September 11 and January 10 were both performed following a heavy rainy period, therefore leading to more conductive (less resistive) values than measured in drier soils.

ELECTROMAGNETIC CONDUCTIVITY

Electromagnetic (EM) conductivity surveys map the actual conductivity of the ground, although it is generally the variations in the measured conductivity, rather than absolute values, which are used to delineate anomalous features. The EM meter measures two phases of induced magnetic field; the first is the quadrature phase component which is the ground conductivity measurement. The second is the inphase component which is the ratio of the induced to primary magnetic field and a strong indicator of buried metallic objects. In addition, the instrument can be operated in two different modes: vertical and horizontal. In vertical dipole mode, the depth of penetration is typically 20 feet, while in horizontal mode the depth of penetration is typically 10 feet.

On September 12, 1996, electromagnetic conductivity surveys were conducted at the site using a Geonics EM 31 meter. These initial surveys were conducted on a three-foot grid spacing with both quadphase and inphase readings in the vertical and horizontal dipole modes. These EM surveys are summarized in Figures 8a, 8b, 8c, and 8d, corresponding to the four respective modes: vertical dipole/quad phase, horizontal dipole/quad phase, vertical dipole/inphase, and horizontal dipole/inphase.

The vertical and horizontal dipole quadphase readings confirm those of the soil resistivity unit, that is, the presence of a resistive sandy layer running parallel and adjacent to the seepage basin fence and changing to a less resistive clayey layer as readings move southward across the site. The horizontal dipole indicated a low resistivity feature running through the center of the site, later confirmed to be a large abandoned telephone cable. The vertical dipole inphase readings did not show any significant metallic anomalies; however, the horizontal dipole inphase readings detected the old metal fence that borders the K-seepage basin.

On January 10, 1997, a series of post-melt electromagnetic conductivity surveys was conducted using a three-foot grid spacing (Figures 9a, 9b, 9c, and 9d). The surveys were conducted using both vertical and horizontal measurements of the quadphase and inphase readings. As was seen in the magnetometer readings, the response of the electromagnetic conductivity measurements was dominated by the presence of the transformer on the site. The emissions from the transformer so strongly dominated the readings that no subsurface features could be readily identified within the test site area.

GROUND PENETRATING RADAR

Ground penetrating radar (GPR) is a geophysical method that uses radio waves at frequencies ranging from 1 to 1000 MHz to explore soil profiles. The detection capability of GPR relies on a measured change in material properties, specifically the material dielectric constant.

The GPRs were performed using a Sensors & Software PulseEKKO IV unit with antenna frequencies of 200 Mhz. The GPR surveys were conducted along lines running approximately north-south and east-west across the test area (see Figure 10). On September 26, 1996, three initial ground penetrating radar reflection surveys were performed along north-south alignments, designated line Nos. 0, 6, and 12, to provide baseline references. The results are summarized in Appendix C.. No significant features or subsurface anomalies were detected at the site in this pre-melt investigation. Equipment malfunction prevented further surveying of the site at that time.

On December 6, 1996, eleven lines were surveyed at the site for post-melt detection. These lines are given in Appendix C. Lines 0 and 12 were used as control lines that did not pass directly over any of the vitrified masses. The remaining profiles either passed directly over the igneous masses, or one to two feet either side of the masses. The GPR profiles show the vitrified masses only when the survey is performed directly over the center of the vitrified mass and when the vitrified mass is rather large. Figures 11 and 12 show the profile lines performed along line 4-EW and line 34.6 N-S. Both GPR profiles indicate the large vitrified mass (double column) located at the southwest corner of the test area. Nevertheless, none of the GPR profiles were able to clearly detect the single plasma melt.

SEISMIC WAVE GEOPHYSICS

To help characterize the site prior to the plasma vitrification demonstration, crosshole tests (CHT) and spectral analysis of surface waves (SASW) tests were performed to determine the soil shear wave velocity variation with depth. These methods impose a dynamic excitation at a source location and record the resulting particle motion at receiver locations below or along the ground surface. These tests concentrated on the measurement of shear wave velocities at the site. The crosshole test is capable of directly measuring both compression (P) and shear (S) waves. The SASW measures surface waves or Rayleigh waves, however, the shear wave and Rayleigh wave are closely related and differ by only a few percent.

Shear wave velocities are evaluated by determining the arrival time of seismic waves at the receiver positions. The shear wave velocity (V_s) of a material is a function of the low-strain shear modulus (G_{max}) and mass density (ρ) through the following relationship:

$$V_s = \sqrt{\frac{G_{max}}{\rho}}$$

To determine velocities from the crosshole test (Hoar & Stokoe, 1978), arrival times of propagating waves are estimated from the particle motion measurements and divided into the travel path distance, which is assumed to be the horizontal distance between source and receiver. Procedures for the crosshole test are outlined in ASTM Standard D-4428 and require the hammer source and receivers to be placed downhole, normally in cased boreholes.

The surface wave technique is more complex and involves using spectral analysis to find a dispersion curve (surface wave velocity vs. wavelength) which is then followed by inversion to obtain the shear wave velocity profile (Stokoe, et al. 1989). In contrast to the CHT, the SASW requires no boreholes and all measurements are taken at the ground surface. Specific detailing is not achieved with this technique, however, and the SASW provides averaged readings over the area surveyed.

Pre-Vitrification Crosshole and Surface Wave Procedures

The preliminary crosshole test at the K-basin site used 4 eight-foot deep boreholes as shown in Figure 13. The boreholes were cased with 3-inch diameter PVC casing, and the annular space between the soil and the casing was filled with sand. One hole was used as the source borehole, and the other 3 holes used for placing the receivers. The distances between the source and receivers 1, 2, and 3 were 3.5 feet, 15.5 feet, and 6.25 feet, respectively. A mechanical hammer was used for the source, while geophones, which measure particle velocity, were used as the receivers. Both the hammer and the receiver were placed at the same depth below the ground surface and coupled to the borehole wall by inflating a pneumatic bladder. The hammer was then triggered and the resulting particle velocity time history was measured at the receivers. This procedure was repeated in one foot increments to a total depth of seven feet.

The SASW test is non-invasive and uses a source and two receivers along the surface of the soil to record particle motion (Stokoe, et al. 1989). The source is an electro-mechanical shaker, which oscillates at varying frequencies, allowing for deeper depths to be measured at larger wavelengths. The receivers are geophones similar to the ones used in the crosshole test and measure particle velocity. To perform the test, the shaker was placed at one edge of the 50 ft x 50 ft test site. The first receiver was placed 3 feet away from the shaker and the second receiver was placed 6 feet away from the shaker along the same line. This configuration is also shown in Figure 13. Successive measurements are made by doubling the spacing between source and first receiver and between the two receivers each time.

The initial profiles of shear wave velocity (V_s) in the native slightly clayey sand material are shown in Figure 14. Both the CHT and SASW confirm a V_s profile increasing from about 400 feet/sec to 550 feet/sec within the exploration depths of 7 feet.

Post-Vitrification Crosshole and Surface Wave Procedures

Crosshole and surface wave tests were conducted again at the site, after the plasma experiments in order to gain an understanding of how the shear modulus changed due to the vitrification. The final crosshole tests include one test across the single-bulb and one test across the double-bulb. For each test, there is a source borehole and one receiver borehole positioned on opposite sides of the bulb(s). Figure 15 shows this configuration. At approximately one foot from the outer perimeter of the bulb, the boreholes were hand-augered with a 3-inch auger to a depth of one foot, and the source and receiver were placed at the bottom of their respective holes. The travel time of the shear wave was measured by triggering the source and recording the particle motion at the receiver position. The test was repeated in 1-foot increments to a total depth of 9 feet.

It should be noted that the post-vitrification wave velocities do not represent the velocity of the vitrified bulb but a combination of the bulb and the soil as shown in Figure 16. The length of the travel path through the soil in both cases is approximately the same, but the travel path through the double-bulb is approximately twice the length of that in the single-bulb. Thus, it would be expected that the velocity through the double-bulb would be greater. The results seem to agree with this reasoning.

Post-magmavication SASW tests were conducted over the double bulb area. Pre- and post-magmavication measurements were compared using the experimental dispersion curves directly. Figure 17 shows the comparison between the two dispersion curves. The post-magmavication dispersion curve shows only about a 50 ft/sec increase in the measured Rayleigh wave velocities for wavelengths of 5 to 9 feet. There are two reasons for observing only a small increase in Rayleigh wave velocity: (1) SASW tests are not well-suited for detecting subsurface anomalies with limited horizontal dimensions such as the magmavication bulbs and (2) SASW tests tend to average subsurface properties over large distances and depths.

The results of the crosshole tests (CHT) across the single bulb are compared with the original baseline values of V_s in Figure 18. These tests showed an increase in V_s throughout the exploration depth, increasing from an average of about 450 fps in original soil to about 650 fps in the vitrified zone. Figure 19 shows a greater increase measured in CHT across the double bulb, with V_s increased from about 450 fps to 1000 fps. Again, this is partially explained through Figure 16.

DISCUSSION

The results of the field plasma magmavication at K-basin appears to have been successful in transforming firm sands into hard obsidian-like rock material. Following the site characterization program in January, the igneous products were exhumed by WSRC for verification and visual examination of the materials. Sizes, dimensions, and weights of the three bulbs were recorded

and provided to us for review. Data are summarized in Table 3 along with the results from laboratory series of plasma experiments on various soils, including the SRS sands. The higher energy and power levels applied by the SRS project resulted in the largest created masses of igneous product by this process to date. Figure 20 illustrates the summary showing that the size of the vitrified mass increases with power consumption. The field tests appear to show higher efficiency than the laboratory series.

Table 5. Sizes of Vitrified Masses Created in Laboratory and Field Experiments.

*Test No.	Initial Soil Type	Initial Water Content (%)	Final Created Mass (kg)	Torch Power Capacity (kW)	Average Applied Power Level (kW)	Cumulative Power Consumption (kW-hr)
L-1A	Piedmont Silty Sand	18.3	38	200	180	180
L-2A	Piedmont Silty Sand	15.4	49	200	172	172
L-3A	Piedmont Silty Sand	30.9	40	200	181	181
L-5B	Piedmont Silty Sand	17.9	31	100	74	74
L-6B	Piedmont Silty Sand	29.7	26	100	71	71
L-7B	Georgia Kaolin	22.7	18	100	65	65
L-8B	Georgia Kaolin	26.1	12	100	61	61
L-9B	Georgia Kaolin	30.6	20	100	79	79
L-11B	Georgia Kaolin	17.4	13	100	56	56
L-12B	Georgia Kaolin	14.6	11	100	56	56
* L-13B	20/30 Silica Sand	4.3	12	100	63	63
* L-10B	Tyndall Beach Sand	4.1	21	100	62	75
L-S-1	SRS slightly clayey Sand	8.3	66	100	80	428
L-S-2	SRS slightly clayey Sand	10.0	40**	100	68	294
L-S-3	SRS slightly clayey Sand	31.4	65	100	60	350
L-S-4	SRS slightly clayey Sand	8.3	89	100	96	624
L-S-5	SRS slightly clayey Sand	8.3	186	200	200	1100
L-S-6	SRS slightly clayey Sand	8.3	139	200	200	674
L-S-7	SRS slightly clayey Sand	11.3	38	100	96	128
F-K-1	SRS slightly clayey Sand	12.4	272	1000	650	870
F-K-2	SRS slightly clayey Sand	12.4	544	1000	650	1740
F-K-3	SRS slightly clayey Sand	12.4	567	1000	650 to 950	1423

***NOTES:**

L = Laboratory Chamber Tests:

1. Test Series A and B reported by Beaver and Mayne (1995)
2. Test Series L-S (number 1 through 6) reported by Waggener (1996).
3. Test L-S-7 reported by Schneider (1997).

F = Field Experiments at K-basin, SRS, Aiken (reported herein).

** Total mass of melt + crust = 65 kg

FUTURE EXPERIMENTS AND RECOMMENDED RESEARCH

Site Characterization Methods

The field trials using a variety of environmental geophysics tools for site characterization (magnetometer, EM, GPR, resistivity) were of limited success here in delineating the presence, size, and extent of igneous products created by the plasma process. It is noted, however, that the site characterization technologies attempted here were more or less established for mapping features deeper than the very shallow results accomplished at K-basin. The current torch configuration has right-angle ports for water and gas input, thus restricting depths of application on this test program (i.e., < 6 feet). However, in many other situations and with an improved field torch having axial inputs of air, water, and electricity, it is possible that depths of 20 to 40 feet or more might be treated with this process.

Further field experimentation with plasma technology should be conducted to better define the technical aspects of the process, increased productivity, and optimization of results. Specific to the site characterization issues, additional studies could be implemented to re-evaluate the technologies tried herein, but without the electromagnetic interference of an electrical transformer. For all test, closer grid spacings on the order of 1 to 2 feet apart might register some detection of very shallow features. For resistivity surveys, closer Wenner arrays of 1 foot are possible. For GPR, additional operational frequencies could prove effective, yet require different size antennas. Some recent developments in colorized processing of GPR data aid in the clarity in deciphering of the data. Also, a new form of GPR, termed georadar, is now available that provides a full frequency sweep, thus offering more flexibility in the detection of different and variable subsurface features beneath the ground surface. Forms of geotomography have also been developed that utilize multiple sets of seismic wave geophones or downhole resistivity electrodes and allow for a 2-d or 3-d picture to be developed from many simultaneous measurements.

Subsurface Placement of Plasma Torches

The use of nontransferred arc plasma torches in areas underlain by soils contaminated with hazardous wastes, mixed wastes, and radioactive materials presents additional difficulties in implementation. In order to minimize exposure of field personnel to buried unknowns and hazardous materials, boreholes advanced by standard auger or rotary drilling techniques is undesirable. Instead, torch access could be provided by creating vertical holes formed by direct push technology, pile driving, mandrels, or other novel construction methods. Some of these concepts that produce no cuttings or earth spoil are discussed as follows:

1. Mandrel-driving. If the native soils are self-supporting (i.e., non-caving), a full-displacement mandrel could be driven to form a vertical columnar cavity in the soil. A large vibroflot (vibrator) could also be used to create this cavity.
2. Closed-end pipe piles. Driven steel pipe with closed end could be driven using standard diesel hammers or hydraulic pile drivers or resonant vibrators to reach the desired depth. The pile would serve as casing to prevent hole collapse during insertion and extraction of the plasma torch. However, use of piles in this manner would make them sacrificial to the remediation program.

3. DeWaal Method. A new Belgian pile system, similar to cast-in-place concrete piles or drilled shafts, is available that utilizes two sets of special drilling bits during drilling. In this process, a high-capacity torque is applied to the front drill bit to remove soil and form a cavity. As the cuttings rise towards the surface, the second set of flights shoves the cuttings laterally 360° into the surrounding ground so that no spoils are accumulated at the ground surface.

4. Vibroflot-Torch. A re-designed plasma torch, complete with offgas portal vents, can be driven into the ground using a conventional vibrotation probe (Brown, 1977). An expendable dummy cone tip could be used on the torch face to facilitate penetration. An outer annulus or concentric ring (or piping) could be used to collect offgases directly at depth, then transferred directly to an offgas treatment facility. Production melting works would be expedient since the hole placement and torch placement are simultaneous.

CONCLUSIONS

During a full-scale demonstration of nontransferred arc plasma technology to melt soils in place, several available nondestructive testing methods were implemented to evaluate their potential in discerning the igneous products formed from magmavication. The methods investigated included environmental geophysical techniques (magnetics, resistivity, electromagnetic conductivity, and ground penetrating radar) and seismic wave geophysics (crosshole testing and spectral analysis of surface waves). The methods of spectral analysis of surface waves (SASW) and ground penetrating radar (GPR) were able to detect the double columns of vitrified material, but not recognize the smaller single column that was formed. In all cases, crosshole testing (CHT) successfully detected the presence of igneous rock product within the original sand medium, however, required the installation of boreholes in advance of testing in order to obtain wave measurements.

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Figure 1. Site Plan of K Seepage Basin at Savannah River Plant, South Carolina.

Scale: 1 inch = 100 feet

Figure 2. Location of Plasma Demo Area at K-Seepage Basin.

Figure 3. Boring Layout for Soil Sampling and Standard Penetration Tests (SPT).

Standard Penetration Test (SPT) Data
K-Area, Plasma Demo, Aiken, SC

Figure 4. Summary of SPT-N Value Resistances in slightly clayey sands.

Sieve Analysis Summary - SS1

Figure 5. Representative grain size and hydrometer analyses of slightly clayey sands.

Magnetometer Data - Final Site Characterization
Savannah River Site - K Reactor
9 JAN 97

Figure 6b.

Apparent Soil Resistivity - Initial Site Characterization
Savannah River Site - K Reactor
11 SEP 96

Figure 7a.

Apparent Soil Resistivity - Final Site Characterization
Savannah River Site - K Reactor
6 DEC 96

Figure 7b.

Apparent Soil Resistivity - Final Site Characterization
Savannah River Site - K Reactor
10 JAN 97

Figure 7c.

Electromagnetic Conductivity
Vertical Dipole, Quad Phase - Initial Site Characterization
Savannah River Site
12 SEP 96

Figure 8a.

Electromagnetic Conductivity
Horizontal Dipole, Quad Phase - Initial Site Characterization
Savannah River Site - K Reactor
12 SEP 96

Figure 8b.

Electromagnetic Conductivity
Vertical Dipole, InPhase - Initial Site Characterization --
Savannah River Site - K Reactor
12 SEP 96

Figure 8c.

Figure 8d.

Electromagnetic Conductivity
Vertical Dipole, Quad Phase - Final Site Characterization -
Savannah River Site - K Reactor
10 JAN 97

Figure 9a.

Electromagnetic Conductivity
Horizontal Dipole, Quad Phase - Final Site Characterization
Savannah River Site - K Reactor
10 JAN 97
Figure 9b.

Electromagnetic Conductivity
Vertical Dipole, InPhase - Final Site Characterization
Savannah River Site - K Reactor
10 JAN 97

Figure 9c.

Electromagnetic Conductivity
Horizontal Dipole, InPhase - Final Site Characterization
Savannah River Site - K Reactor
10 JAN 97

Figure 9d.

GPR Profile Lines - Final Site Characterization
Savannah River Site - K Reactor
9 JAN 97

Figure 10.

Figure 11. Post-melt GPR results along line 4-EW showing double bulb.

Figure 12. Post-melt GPR results along line 34.6 (north) showing double bulb.

Figure 13. Layout of Pre-Melt Crosshole and SASW Geophysical Surveys.

Figure 14. Pre-Melt Profiles of Shear Wave Velocity in Native Sands.

Figure 15. Layout of Post-Melt Crosshole and SASW Geophysical Surveys.

Figure 16. Possible Single- and Double-Bulb Profiles for Crosshole Testing.

Figure 17. Dispersion Curves from Rayleigh (Surface) Waves over Double Bulb.

Figure 18. Pre- and Post-Melt Crosshole Results across Single Bulb.

Figure 19. Pre- and Post-Melt Crosshole Results across Double Bulb.

Figure 20. Measured Mass of Igneous Product vs. Applied Power Consumption.

APPENDICES

Summary Report Site Characterization Program Demonstration of Nontransferred-Arc In-Situ Plasma Magmavication K-Basin, Savannah River Site

prepared by

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submitted to

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Westinghouse Savannah River Company
Aiken, South Carolina**

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March 21, 1997

Appendix A

Standard Penetration Tests and Soil Boring Records

Conducted by AEI Drilling for WSRC
South of K-Seepage Basin, Aiken, S.C.
Logged in Field by GT, October 11, 1996

Depth (ft)	Visual soil description	Depth (ft)	N*	N
0.0	Gray silty fine sand with traces of clay (SM)	0.0	4	12
0.8		0.5	8	
1.4	Tan brown clayey fine sand (SP-SC)	1.0	9	28
		1.5	19	
	Red brown clayey sand (SC)	2.0	10	22
2.8		2.5	12	
3.3	Light tan clean sand (SP)	3.0	11	29
		3.5	18	
4.0	Brown clayey sand (SC)	4.0	10	20
		4.5	10	
5.1	Light tan silty sand (SM)	5.0	12	27
		5.5	15	
6.0	Dark gray silty sand (SP-SM)	6.0	16	23
		6.5	7	
	Brown sand with traces of caly (SP)	7.0	6	12
		7.5	6	
8.0	Light tan sand (SP)	8.0		

Boring Number:

SS1

N* = Penetration in blows per 6"

Date Drilled:

10/11/96

N = Penetration in blows per 12"

Depth (ft)	Visual soil description	Depth (ft)	N*	N
0.0	Tan brown desiccated clayey sand (SC)	0.0	3	11
		0.5	8	
1.0		1.0	12	
	Tan brown sand with clay traces (SP-SC)	1.5	21	33
2.0		2.0	16	
		2.5	9	
	Orange tan to tan brown clayey sand (SC)	3.0	16	34
3.0		3.5	18	
		4.0	9	
	Black to brown silty sands with organics (SM)	4.5	6	15
4.0		5.0	8	
		5.5	11	
	Gray to light tan silty fine sand (SM)	6.0	15	23
		6.5	8	
6.8		7.0	7	
	Light tan clean sand with traces of silt (SP)	7.5	5	12
		8.0		
8.0				

Boring Number:

SS2

N* = Penetration in blows per 6"

Date Drilled:

10/11/96

N = Penetration in blows per 12"

Appendix B

Laboratory Test Data
Grain Size Analyses
Hydrometer Analyses
Direct Shear Box Tests
Moisture Contents
Unit Weights

Conducted at Geosystems Laboratory
School of Civil & Environmental Engineering
Georgia Institute of Technology
October-December, 1996

Sieve Analysis Summary

Project: Plasma Torch Demo
Location: Savannah River Site
Hole No: SPT1
Depth: 0 to 8 feet
Classified by: Kimberly Finke

DEPTH (feet)	% FINES	CLASSIFICATION
0-2	8.33	SP-SM or SP-SC
2-4	22.43	SM-SC
4-5	12.69	SM-SC
5-6	8.30	SP-SM or SP-SC
6-7	12.34	SP-SM or SP-SC
7-8	6.32	SP-SM or SP-SC

Sieve Analysis Summary - SS1

Project: Plasma Demo
Hole #: SS1
Classified by: Kimberly Finke

Depth: 0-2 feet

Sieve #	Grain Diam(mm)	Wt. of sieve(g)	Soil+sieve(g)	Mass Retained(g)	Mass Passing(g)	%Passing
4	4.750	586.90	587.82	0.92	465.01	1.00
20	0.850	412.20	453.30	41.10	423.91	0.91
40	0.425	289.15	363.95	74.80	349.11	0.75
60	0.250	366.29	525.35	159.06	190.05	0.41
100	0.150	426.66	522.62	95.96	94.09	0.20
200	0.075	333.53	388.80	55.27	38.82	0.08
pan		377.40	416.22	38.82	0.00	0.00
Total wt.:				465.93		
Fines % =				8.33		

Depth: 2-4 feet

Sieve #	Grain Diam(mm)	Wt. of sieve(g)	Soil+sieve(g)	Mass Retained(g)	Mass Passing(g)	%Passing
4	4.750	586.90	593.69	6.79	440.92	0.98
20	0.850	412.20	462.67	50.47	390.45	0.87
40	0.425	289.15	340	50.85	339.60	0.76
60	0.250	366.29	481.6	115.31	224.29	0.50
100	0.150	426.66	503.84	77.18	147.11	0.33
200	0.075	333.53	380.24	46.71	100.40	0.22
pan		377.40	477.8	100.40	0.00	0.00
Total wt:				447.71		
Fines % =				22.43		

Depth: 4-5 feet

Sieve #	Grain Diam(mm)	Wt. of sieve(g)	Soil+sieve(g)	Mass Retained(g)	Mass Passing(g)	%Passing
4	4.750	586.90	597.57	10.67	443.24	0.98
20	0.850	412.20	470.01	57.81	385.43	0.85
40	0.425	289.15	344.53	55.38	330.05	0.73
60	0.250	366.29	493.76	127.47	202.58	0.45
100	0.150	426.66	516.21	89.55	113.03	0.25
200	0.075	333.53	388.94	55.41	57.62	0.13
pan		377.40	435.02	57.62	0.00	0.00
Total wt:				453.91		
Fines % =				12.69		

Depth: 5-6 feet

Sieve #	Grain Diam(mm)	Wt. of sieve(g)	Soil+sieve(g)	Mass Retained(g)	Mass Passing(g)	%Passing
4	4.750	586.90	587.74	0.84	355.23	1.00
20	0.850	412.20	422.56	10.36	344.87	0.97
40	0.425	289.15	340.07	50.92	293.95	0.83
60	0.250	366.29	520.55	154.26	139.69	0.39
100	0.150	426.66	496.6	69.94	69.75	0.20
200	0.075	333.53	373.71	40.18	29.57	0.08
pan		377.40	406.97	29.57	0.00	0.00
Total wt:				356.07		
Fines % =				8.30		

Depth: 6-7 feet

Sieve #	Grain Diam(mm)	Wt. of sieve(g)	Soil+sieve(g)	Mass Retained(g)	Mass Passing(g)	%Passing
4	4.750	586.90	602.66	15.76	386.55	0.96
20	0.850	412.20	457.24	45.04	341.51	0.85
40	0.425	289.15	321.07	31.92	309.59	0.77
60	0.250	366.29	505.43	139.14	170.45	0.42
100	0.150	426.66	501.46	74.80	95.65	0.24
200	0.075	333.53	379.54	46.01	49.64	0.12
pan		377.40	427.04	49.64	0.00	0.00
Total wt:				402.31		
Fines % =				12.34		

Depth: 7-8 feet

Sieve #	Grain Diam(mm)	Wt. of sieve(g)	Soil+sieve(g)	Mass Retained(g)	Mass Passing(g)	%Passing
4	4.750	586.90	586.9	0.00	485.72	1.00
20	0.850	412.20	430.14	17.94	467.78	0.96
40	0.425	289.15	341.05	51.90	415.88	0.86
60	0.250	366.29	586.99	220.70	195.18	0.40
100	0.150	426.66	534.3	107.64	87.54	0.18
200	0.075	333.53	390.37	56.84	30.70	0.06
pan		377.40	408.1	30.70	0.00	0.00
Total wt:				485.72		
Fines % =				6.32		

1.

SS1-0-2ft

1.

SS1- 2-4 feet

SS1-4-5 ft

SS1 - 5-6 feet

SS1 - 6-7 feet

SS1 - 7-8 feet

SS1- 2-4 feet -Sieve/Hydrometer

2

SS1 - 6-7ft Sieve/Hydrometer

Hydrometer Data (Passing #200 Sieve)

Unit wt. of soil grains = 2.7

Unit wt. of water at 22 C = 0.9978

Viscosity of water at 22 C = 9.61 millipoises =

9.80E-06 gram sec/cm²

Unit wt. of water at 21 C = 0.998

Z' = 16.2 cm

Vh/Aj = 2.4 cm

Rc = Ractual - zero correction + Ct

Zr = 15 cm

rw = 7 (at 21C)

rw corrected for meniscus = 8 ... L = 15 cm

Meniscus correction: 1

K * = .0131

Ct (for 22C) = 0.4

a = .99

SS1- 2-4 feet

mass = 47.56 g

Date	Time	Elapsed Time (min)	Elapsed Time (sec)	Effective Diameter (mm)	Hydrometer Reading (Ractual)	Corrected for Meniscus (R)	Zero Correction	Rc	% Finer	Equivalent % Finer
15-Jan	10:37 AM	2	120	2.79E-02	50	51	7	44.4	92.42%	20.73%
	10:40 AM	5	300	1.76E-02	47	48	7	41.4	86.18%	19.33%
	10:50 AM	15	900	1.02E-02	45	46	7	39.4	82.01%	18.40%
	11:05 AM	30	1800	7.20E-03	43	44	7	37.4	77.85%	17.46%
	11:35 AM	60	3600	5.09E-03	42	43	7	36.4	75.77%	17.00%
	2:45 PM	250	15000	2.49E-03	39	40	7	33.4	69.52%	15.59%
16-Jan	10:35 AM	1440	86400	1.04E-03	37	38	7	31.4	65.36%	14.66%
17-Jan	10:30 AM	2875	172500	7.35E-04	36	37	7	30.4	63.28%	14.19%
20-Jan	11:17 AM	7242	434520	4.63E-04	34.5	35.5	7	28.9	60.16%	13.49%

SS1- 4-5 feet

mass = 49.80 g

Date	Time	Elapsed Time (min)	Elapsed Time (sec)	Effective Diameter (mm)	Hydrometer Reading (Ractual)	Corrected for Meniscus (R)	Zero Correction	Rc	% Finer	Equivalent % Finer
15-Jan	10:53 AM	2	120	2.79E-02	44	45	7	38.4	76.34%	9.69%
	10:56 AM	5	300	1.76E-02	40	41	7	34.4	68.39%	8.68%
	11:06 AM	15	900	1.02E-02	35	36	7	29.4	58.45%	7.42%
	11:21 AM	30	1800	7.20E-03	32	33	7	26.4	52.48%	6.66%
	11:51 AM	60	3600	5.09E-03	30	31	7	24.4	48.51%	6.16%
	3:01 PM	250	15000	2.49E-03	25	26	7	19.4	38.57%	4.89%
16-Jan	10:51 AM	1440	86400	1.04E-03	20.5	21.5	7	14.9	29.62%	3.76%
17-Jan	10:30 AM	2859	171540	7.37E-04	19	20	7	13.4	26.64%	3.38%
20-Jan	11:18 AM	7227	433620	4.64E-04	16	17	7	10.4	20.67%	2.62%

SS1- 6-7 feet

mass = 49.46 g

Date	Time	Elapsed Time (min)	Elapsed Time (sec)	Effective Diameter (mm)	Hydrometer Reading (Ractual)	Corrected for Meniscus (R)	Zero Correction	Rc	% Finer	Equivalent % Finer
15-Jan	11:16 AM	2	120	2.79E-02	35	36	7	29.4	58.85%	7.47%
	11:19 AM	5	300	1.76E-02	38	39	7	32.4	64.85%	8.23%
	11:34 AM	15	900	1.02E-02	35	36	7	29.4	58.85%	7.47%
	11:44 AM	30	1800	7.20E-03	34	35	7	28.4	56.85%	7.21%
	12:14 PM	60	3600	5.09E-03	31	32	7	25.4	50.84%	6.45%
	3:24 PM	250	15000	2.49E-03	27	28	7	21.4	42.83%	5.44%
16-Jan	11:14 AM	1440	86400	1.04E-03	22	23	7	16.4	32.83%	4.17%
17-Jan	10:30 AM	2836	170160	7.40E-04	20.5	21.5	7	14.9	29.82%	3.78%
20-Jan	11:20 AM	7206	432360	4.64E-04	20	21	7	14.4	28.82%	3.66%

Project: Plasma Demo
Hole #: SS1
Classified by: Kimberly Finke

Depth: 0-2 feet							%Passing
Sieve #	Grain Diam(mm)	Wt. of sieve(g)	Soil+sieve(g)	Mass Retained(g)	Mass Passing(g)		0-2 feet
4	4.750	586.90	587.82	0.92	465.01		99.80%
20	0.850	412.20	453.30	41.10	423.91		90.98%
40	0.425	289.15	363.95	74.80	349.11		74.93%
60	0.250	366.29	525.35	159.06	190.05		40.79%
100	0.150	426.66	522.62	95.96	94.09		20.19%
200	0.075	333.53	388.80	55.27	38.82		8.33%
pan		377.40	416.22	38.82	0.00		0.00%
Total wt.:				465.93			
Fines % =				8.33			

Depth: 2-4 feet							%Passing
Sieve #	Grain Diam(mm)	Wt. of sieve(g)	Soil+sieve(g)	Mass Retained(g)	Mass Passing(g)		2-4 feet
4	4.750	586.90	593.69	6.79	440.92		98.48%
20	0.850	412.20	462.67	50.47	390.45		87.21%
40	0.425	289.15	340	50.85	339.60		75.85%
60	0.250	366.29	481.6	115.31	224.29		50.10%
100	0.150	426.66	503.84	77.18	147.11		32.86%
200	0.075	333.53	380.24	46.71	100.40		22.43%
pan		377.40	477.8	100.40	0.00		0.00%
Total wt:				447.71			
Fines % =				22.43			

Depth: 4-5 feet							%Passing
Sieve #	Grain Diam(mm)	Wt. of sieve(g)	Soil+sieve(g)	Mass Retained(g)	Mass Passing(g)		4-5 feet
4	4.750	586.90	597.57	10.67	443.24		97.65%
20	0.850	412.20	470.01	57.81	385.43		84.91%
40	0.425	289.15	344.53	55.38	330.05		72.71%
60	0.250	366.29	493.76	127.47	202.58		44.63%
100	0.150	426.66	516.21	89.55	113.03		24.90%
200	0.075	333.53	388.94	55.41	57.62		12.69%
pan		377.40	435.02	57.62	0.00		0.00%
Total wt:				453.91			
Fines % =				12.69			

Depth: 5-6 feet

Sieve #	Grain Diam(mm)	Wt. of sieve(g)	Soil+sieve(g)	Mass Retained(g)	Mass Passing(g)	%Passing 5-6 feet
4	4.750	586.90	587.74	0.84	355.23	99.76%
20	0.850	412.20	422.56	10.36	344.87	96.85%
40	0.425	289.15	340.07	50.92	293.95	82.55%
60	0.250	366.29	520.55	154.26	139.69	39.23%
100	0.150	426.66	496.6	69.94	69.75	19.59%
200	0.075	333.53	373.71	40.18	29.57	8.30%
pan		377.40	406.97	29.57	0.00	0.00%
Total wt:				356.07		
Fines % =				8.30		

Depth: 6-7 feet

Sieve #	Grain Diam(mm)	Wt. of sieve(g)	Soil+sieve(g)	Mass Retained(g)	Mass Passing(g)	%Passing 6-7 feet
4	4.750	586.90	602.66	15.76	386.55	96.08%
20	0.850	412.20	457.24	45.04	341.51	84.89%
40	0.425	289.15	321.07	31.92	309.59	76.95%
60	0.250	366.29	505.43	139.14	170.45	42.37%
100	0.150	426.66	501.46	74.80	95.65	23.78%
200	0.075	333.53	379.54	46.01	49.64	12.34%
pan		377.40	427.04	49.64	0.00	0.00%
Total wt:				402.31		
Fines % =				12.34		

Depth: 7-8 feet

Sieve #	Grain Diam(mm)	Wt. of sieve(g)	Soil+sieve(g)	Mass Retained(g)	Mass Passing(g)	%Passing 7-8 feet
4	4.750	586.90	586.9	0.00	485.72	100.00%
20	0.850	412.20	430.14	17.94	467.78	96.31%
40	0.425	289.15	341.05	51.90	415.88	85.62%
60	0.250	366.29	586.99	220.70	195.18	40.18%
100	0.150	426.66	534.3	107.64	87.54	18.02%
200	0.075	333.53	390.37	56.84	30.70	6.32%
pan		377.40	408.1	30.70	0.00	0.00%
Total wt:				485.72		
Fines % =				6.32		

Sieve Analysis Summary - SS1

Direct Shear Test of SPT1 - 1.5 feet

Modified Mohr Coulomb of SPT1a - 1.5 feet

Tue Nov 12 1996

DIRECT SHEAR TEST DATA

Project: Plasma Torch Demo
Test No.:1
Boring No.: SPT1
Sample No.: 1

Location : Savannah River Site
Sample Type : Sand
Test Date : 11/12/9
Depth : 1.5 ft

Confining Pressure: 1 tsf= 107.3 kPa
Height after consolidation: 0.788 in
Initial Diameter: 2.5 in
Initial Area: 4.91 in^2
Volume: 3.86908 in^3 63.38713764 cm^3
Mass of Soil: 154.79 g
Moist Unit Weight: 2.441978069 g/cm^3
Moisture Content: 14.37121324 % Mass(dry,g): 135.34
Dry Unit Weight: 2.135133484 g/cm^3
Strain Rate: 0.01 in/min
Sample Shape: Circular
Friction Angle: 33.1 degrees

HORIZONTAL DISPLACEMENT (in)	% HORIZONTAL DISPLACEMENT (%)	HORIZONTAL FORCE (lb)	VERTICAL DISPLACEMENT (in)	% VERTICAL DISPLACEMENT (%)	NORMAL STRESS (lb/in^2)	SHEAR STRESS (psi)	SHEAR/ VERTICAL STRESS	SHEAR STRESS kPa
0	0.00%	0.25	0	0.00%	13.93	0.05	0.004	0.34
0.013	0.52%	23.02	0.003	0.78%	13.93	4.69	0.337	32.34
0.016	0.64%	24.13	0.004	1.04%	13.93	4.91	0.353	33.86
0.017	0.68%	26.34	0.004	1.04%	13.93	5.37	0.385	37.03
0.02	0.80%	29.03	0.005	1.30%	13.93	5.91	0.424	40.76
0.022	0.88%	30.29	0.005	1.30%	13.93	6.17	0.443	42.55
0.024	0.96%	31.08	0.006	1.56%	13.93	6.33	0.454	43.66
0.05	2.00%	36.14	0.009	2.34%	13.93	7.36	0.528	50.76
0.052	2.08%	36.46	0.009	2.34%	13.93	7.43	0.533	51.24
0.071	2.84%	38.99	0.01	2.60%	13.93	7.94	0.57	54.76
0.099	3.96%	40.73	0.01	2.60%	13.93	8.3	0.595	57.24
0.102	4.08%	41.36	0.011	2.86%	13.93	8.43	0.605	58.14
0.104	4.16%	41.2	0.011	2.86%	13.93	8.39	0.602	57.86
0.107	4.28%	41.52	0.011	2.86%	13.93	8.46	0.607	58.34
0.109	4.36%	42.31	0.011	2.86%	13.93	8.62	0.619	59.45
0.111	4.44%	42.31	0.011	2.86%	13.93	8.62	0.619	59.45
0.123	4.92%	42.31	0.011	2.86%	13.93	8.62	0.619	59.45
0.126	5.04%	42.31	0.011	2.86%	13.93	8.62	0.619	59.45
0.128	5.12%	42.94	0.011	2.86%	13.93	8.75	0.628	60.34
0.131	5.24%	42.62	0.011	2.86%	13.93	8.68	0.623	59.86
0.133	5.32%	43.1	0.011	2.86%	13.93	8.78	0.63	60.55
0.135	5.40%	43.41	0.011	2.86%	13.93	8.84	0.635	60.97
0.138	5.52%	43.41	0.011	2.86%	13.93	8.84	0.635	60.97
0.14	5.60%	43.1	0.011	2.86%	13.93	8.78	0.63	60.55
0.162	6.48%	43.57	0.011	2.86%	13.93	8.88	0.637	61.24
0.164	6.56%	44.68	0.011	2.86%	13.93	9.1	0.653	62.76
0.183	7.32%	44.84	0.011	2.86%	13.93	9.13	0.656	62.97
0.186	7.44%	45.15	0.011	2.86%	13.93	9.2	0.66	63.45
0.188	7.52%	44.2	0.011	2.86%	13.93	9.01	0.646	62.14
0.19	7.60%	44.05	0.011	2.86%	13.93	8.97	0.644	61.86
0.193	7.72%	45	0.011	2.86%	13.93	9.17	0.658	63.24
0.195	7.80%	44.36	0.011	2.86%	13.93	9.04	0.649	62.34
0.198	7.92%	45.47	0.011	2.86%	13.93	9.26	0.665	63.86
0.2	8.00%	45.31	0.011	2.86%	13.93	9.23	0.662	63.66
0.202	8.08%	45.31	0.011	2.86%	13.93	9.23	0.662	63.66
0.205	8.20%	45.79	0.011	2.86%	13.93	9.33	0.669	64.34
0.216	8.64%	45.31	0.011	2.86%	13.93	9.23	0.662	63.66
0.226	9.04%	46.42	0.011	2.86%	13.93	9.46	0.679	65.24
0.228	9.12%	46.1	0.011	2.86%	13.93	9.39	0.674	64.76
0.23	9.20%	46.73	0.011	2.86%	13.93	9.52	0.683	65.66
0.247	9.88%	47.21	0.011	2.86%	13.93	9.62	0.69	66.34
0.25	10.00%	47.52	0.011	2.86%	13.93	9.68	0.695	66.76
0.25	10.00%	47.52	0.011	2.86%	13.93	9.68	0.695	66.76

Confining Pressure: 2 tsf= 214.6 kPa
 Height after consolidation: 0.886 in
 Initial Diameter: 2.5 in
 Initial Area: 4.91 in²
 Volume: 4.35 in³ 71.27 cm³
 Mass of Soil: 152.24 g
 Moist Unit Weight: 2.14 g/cm³
 Moisture Content: 10.70 % Mass(dry,g): 137.52
 Dry Unit Weight: 1.93 g/cm³
 Strain Rate: 0.01 in/min

HORIZONTAL DISPLACEMENT (in)	% HORIZONTAL DISPLACEMENT (%)	HORIZONTAL FORCE (lb)	VERTICAL DISPLACEMENT (in)	% VERTICAL DISPLACEMENT (%)	NORMAL STRESS (lb/in ²)	SHEAR STRESS (lb/in ²)	SHEAR/ VERTICAL	SHEAR STRESS kPa
0	0.00%	7.21	0	0.00%	27.69	1.47	0.053	10.14
0.002	0.08%	11.32	0.001	0.09%	27.69	2.31	0.083	15.93
0.003	0.12%	18.75	0.001	0.14%	27.69	3.82	0.138	26.34
0.016	0.64%	46.26	0.005	0.72%	27.69	9.42	0.34	64.97
0.018	0.72%	50.84	0.006	0.81%	27.69	10.36	0.374	71.45
0.02	0.80%	54.48	0.006	0.90%	27.69	11.1	0.401	76.55
0.022	0.88%	56.69	0.007	0.99%	27.69	11.55	0.417	79.66
0.024	0.96%	59.07	0.008	1.08%	27.69	12.03	0.435	82.97
0.04	1.60%	76.93	0.011	1.81%	27.69	15.67	0.566	108.07
0.042	1.68%	80.57	0.011	1.90%	27.69	16.41	0.593	113.17
0.044	1.76%	83.26	0.011	1.99%	27.69	16.96	0.612	116.97
0.047	1.88%	84.84	0.011	2.12%	27.69	17.28	0.624	119.17
0.05	2.00%	85.15	0.011	2.26%	27.69	17.35	0.626	119.66
0.052	2.08%	88.47	0.012	2.35%	27.69	18.02	0.651	124.28
0.054	2.16%	89.11	0.012	2.44%	27.69	18.15	0.655	125.17
0.069	2.76%	97.17	0.012	3.12%	27.69	19.79	0.715	136.48
0.072	2.88%	100.01	0.012	3.25%	27.69	20.37	0.736	140.48
0.074	2.96%	101.44	0.012	3.34%	27.69	20.66	0.746	142.48
0.077	3.08%	102.39	0.012	3.48%	27.69	20.86	0.753	143.86
0.079	3.16%	101.81	0.012	3.57%	27.69	20.76	0.75	143.17
0.081	3.24%	104.44	0.012	3.66%	27.69	21.28	0.768	146.76
0.083	3.32%	106.18	0.012	3.75%	27.69	21.63	0.781	149.17
0.097	3.88%	109.5	0.012	4.38%	27.69	22.31	0.806	153.86
0.099	3.96%	111.4	0.012	4.47%	27.69	22.69	0.819	156.48
0.102	4.08%	112.5	0.012	4.60%	27.69	22.92	0.828	158.07
0.105	4.20%	112.82	0.012	4.74%	27.69	22.98	0.83	158.48
0.107	4.28%	112.03	0.012	4.83%	27.69	22.82	0.824	157.38
0.109	4.36%	115.03	0.012	4.92%	27.69	23.43	0.846	161.59
0.111	4.44%	114.72	0.012	5.01%	27.69	23.37	0.844	161.17
0.114	4.56%	114.08	0.012	5.15%	27.69	23.24	0.839	160.28
0.13	5.20%	114.24	0.011	5.87%	27.69	23.27	0.84	160.48
0.133	5.32%	114.4	0.011	6.00%	27.69	23.31	0.842	160.76
0.135	5.40%	112.66	0.01	6.09%	27.69	22.95	0.829	158.28
0.138	5.52%	112.82	0.01	6.23%	27.69	22.98	0.83	158.48
0.14	5.60%	113.61	0.01	6.32%	27.69	23.14	0.836	159.59
0.142	5.68%	113.14	0.01	6.41%	27.69	23.05	0.832	158.97
0.145	5.80%	112.5	0.01	6.55%	27.69	22.92	0.828	158.07
0.148	5.92%	113.45	0.01	6.68%	27.69	23.11	0.835	159.38
0.149	5.96%	112.98	0.01	6.73%	27.69	23.02	0.831	158.76
0.165	6.60%	110.82	0.01	7.45%	27.69	22.6	0.816	155.86
0.167	6.68%	109.5	0.01	7.54%	27.69	22.31	0.806	153.86
0.169	6.76%	110.61	0.01	7.63%	27.69	22.53	0.814	155.38
0.171	6.84%	109.87	0.009	7.72%	27.69	22.4	0.809	154.48
0.174	6.96%	111.08	0.009	7.86%	27.69	22.63	0.817	156.07
0.176	7.04%	109.87	0.009	7.95%	27.69	22.4	0.809	154.48
0.179	7.16%	108.71	0.009	8.08%	27.69	22.15	0.8	152.76
0.208	8.32%	109.34	0.009	9.39%	27.69	22.27	0.804	153.59
0.21	8.40%	109.18	0.009	9.48%	27.69	22.24	0.803	153.38
0.225	9.00%	110.61	0.009	10.16%	27.69	22.53	0.814	155.38
0.227	9.08%	110.13	0.009	10.25%	27.69	22.44	0.81	154.76
0.229	9.16%	110.61	0.009	10.34%	27.69	22.53	0.814	155.38
0.231	9.24%	109.66	0.009	10.43%	27.69	22.34	0.807	154.07
0.234	9.36%	110.61	0.009	10.56%	27.69	22.53	0.814	155.38
0.236	9.44%	110.29	0.008	10.65%	27.69	22.47	0.811	154.97
0.246	9.84%	110.29	0.008	11.11%	27.69	22.47	0.811	154.97

Confining Pressure: 3 tsf= 321.76 kPa
 Height after consolidation: 0.928 in
 Initial Diameter: 2.5 in
 Initial Area: 4.91 in²
 Volume: 4.56 in³ 74.65 cm³
 Mass of Soil: 157.02 g
 Moist Unit Weight: 2.10 g/cm³
 Moisture Content: 12.58 % Mass(dry,g): 139.47
 Dry Unit Weight: 1.87 g/cm³
 Strain Rate: 0.01 in/min

HORIZONTAL DISPLACEMENT (in)	% HORIZONTAL DISPLACEMENT (%)	HORIZONTAL FORCE (lb)	VERTICAL DISPLACEMENT (in)	% VERTICAL DISPLACEMENT (%)	VERTICAL STRESS (lb/in ²)	SHEAR STRESS (lb/in ²)	SHEAR/ VERTICAL STRESS	SHEAR STRESS kPa
0	0.00%	1.83	0	0.00%	41.84	0.37	0.009	2.55
0.001	0.04%	5.63	0	0.00%	41.84	1.15	0.027	7.93
0.012	0.48%	52.11	0.004	0.43%	41.84	10.62	0.254	73.24
0.014	0.56%	56.06	0.004	0.43%	41.84	11.42	0.273	78.76
0.016	0.64%	62.54	0.005	0.54%	41.84	12.74	0.305	87.86
0.018	0.72%	66.81	0.005	0.54%	41.84	13.61	0.325	93.86
0.02	0.80%	70.45	0.006	0.65%	41.84	14.35	0.343	98.97
0.023	0.92%	72.19	0.006	0.65%	41.84	14.71	0.351	101.45
0.025	1.00%	77.72	0.007	0.75%	41.84	15.83	0.378	109.17
0.028	1.12%	80.25	0.007	0.75%	41.84	16.35	0.391	112.76
0.029	1.16%	83.1	0.008	0.86%	41.84	16.93	0.405	116.76
0.031	1.24%	83.73	0.008	0.86%	41.84	17.06	0.408	117.66
0.043	1.72%	97.17	0.01	1.08%	41.84	19.79	0.473	136.48
0.045	1.80%	98.91	0.01	1.08%	41.84	20.15	0.482	138.97
0.048	1.92%	100.49	0.01	1.08%	41.84	20.47	0.489	141.17
0.05	2.00%	100.17	0.01	1.08%	41.84	20.41	0.488	140.76
0.053	2.12%	103.81	0.01	1.08%	41.84	21.15	0.505	145.86
0.055	2.20%	104.76	0.011	1.19%	41.84	21.34	0.51	147.17
0.057	2.28%	104.76	0.011	1.19%	41.84	21.34	0.51	147.17
0.06	2.40%	105.23	0.011	1.19%	41.84	21.44	0.512	147.86
0.071	2.84%	112.5	0.011	1.19%	41.84	22.92	0.548	158.07
0.074	2.96%	112.82	0.012	1.29%	41.84	22.98	0.549	158.48
0.076	3.04%	114.24	0.012	1.29%	41.84	23.27	0.556	160.48
0.083	3.32%	116.3	0.012	1.29%	41.84	23.69	0.566	163.38
0.097	3.88%	118.35	0.012	1.29%	41.84	24.11	0.576	166.28
0.099	3.96%	120.57	0.012	1.29%	41.84	24.56	0.587	169.38
0.102	4.08%	120.41	0.012	1.29%	41.84	24.53	0.586	169.17
0.104	4.16%	121.67	0.012	1.29%	41.84	24.79	0.592	170.97
0.107	4.28%	121.2	0.012	1.29%	41.84	24.69	0.59	170.28
0.109	4.36%	122.84	0.012	1.29%	41.84	25.04	0.599	172.69
0.111	4.44%	123.89	0.012	1.29%	41.84	25.24	0.603	174.07
0.113	4.52%	123.41	0.012	1.29%	41.84	25.14	0.601	173.38
0.116	4.64%	124.05	0.012	1.29%	41.84	25.27	0.604	174.28
0.13	5.20%	127.05	0.012	1.29%	41.84	25.88	0.619	178.48
0.132	5.28%	128.63	0.012	1.29%	41.84	26.2	0.626	180.69
0.135	5.40%	129.1	0.012	1.29%	41.84	26.3	0.629	181.38
0.145	5.80%	130.53	0.012	1.29%	41.84	26.59	0.636	183.38
0.147	5.88%	131	0.012	1.29%	41.84	26.69	0.638	184.07
0.161	6.44%	133.69	0.012	1.29%	41.84	27.23	0.651	187.79
0.164	6.56%	134.48	0.012	1.29%	41.84	27.4	0.655	188.97
0.166	6.64%	134.8	0.012	1.29%	41.84	27.46	0.656	189.38
0.169	6.76%	134.95	0.012	1.29%	41.84	27.49	0.657	189.59
0.195	7.80%	140.01	0.012	1.29%	41.84	28.52	0.682	196.69
0.204	8.16%	141.44	0.012	1.29%	41.84	28.81	0.689	198.69
0.207	8.28%	141.28	0.012	1.29%	41.84	28.78	0.688	198.48
0.209	8.36%	142.23	0.012	1.29%	41.84	28.97	0.692	199.79
0.225	9.00%	144.44	0.012	1.29%	41.84	29.43	0.703	202.97
0.228	9.12%	144.44	0.012	1.29%	41.84	29.43	0.703	202.97
0.23	9.20%	145.39	0.012	1.29%	41.84	29.62	0.708	204.28
0.233	9.32%	145.7	0.012	1.29%	41.84	29.68	0.709	204.69
0.235	9.40%	145.7	0.012	1.29%	41.84	29.68	0.709	204.69
0.238	9.52%	146.02	0.012	1.29%	41.84	29.75	0.711	205.17
0.24	9.60%	146.65	0.012	1.29%	41.84	29.88	0.714	206.07
0.247	9.88%	146.97	0.012	1.29%	41.84	29.94	0.716	206.48
0.249	9.86%	146.97	0.012	1.29%	41.84	29.94	0.716	206.48

Mon Nov 18, 1996

DIRECT SHEAR TEST DATA

Project : Plasma Torch Demo
Test No. : 2
Boring No. : SPT1
Sample No. : 2
Depth: 3.5 feet

Location: Savannah River Site
Sample Type : Remolded sandy soil
Tested by : Kim Finke
Remarks: Half of soil in shelly tube missing
Moisture Content: 7.88 %

Confining Pressure: 1 tsf = 107.25 kPa = 13.83 psi
Initial Height : 1 in
Height after consolidation : 0.885 in
Initial Diameter: 2.5 in
Initial Area: 4.91 (in²)
Volume: 4.35 (in³) = 71.27 g/(cm³)
Mass of soil (wet): 140.68 g
Moist unit weight: 1.97 g/(cm³)
Mass of soil (dry): 126.94 g
Dry unit weight: 1.78 g/(cm³)
Strain rate: 0.01 in/min

HORIZONTAL DISPLACEMENT (in)	% HORIZONTAL DISPLACEMENT (%)	HORIZONTAL FORCE (lb)	VERTICAL DISPLACEMENT (in)	%VERTICAL DISPLACEMENT (%)	NORMAL STRESS (lb/in ²)	SHEAR STRESS (lb/in ²)	SHEAR/ VERTICAL	SHEAR STRESS (kPa)
0	0.00%	0	0	0.00%	13.83	0.00	0.605	0.00
0.007	0.28%	7.59	0.006	0.68%	13.83	1.55	0.717	10.68
0.01	0.40%	11.07	0.007	0.79%	13.83	2.26	0.768	15.57
0.012	0.48%	13.44	0.009	1.02%	13.83	2.74	0.803	18.91
0.014	0.56%	15.5	0.01	1.13%	13.83	3.16	0.833	21.81
0.063	2.52%	40.16	0.023	2.60%	13.83	8.19	1.196	56.50
0.066	2.64%	40.16	0.024	2.71%	13.83	8.19	1.196	56.50
0.068	2.72%	40	0.024	2.71%	13.83	8.16	1.194	56.28
0.089	3.56%	44.9	0.026	2.94%	13.83	9.16	1.266	63.17
0.092	3.68%	45.69	0.026	2.94%	13.83	9.32	1.278	64.28
0.094	3.76%	46.48	0.027	3.05%	13.83	9.48	1.29	65.39
0.096	3.84%	47.12	0.027	3.05%	13.83	9.61	1.299	66.29
0.099	3.96%	47.27	0.027	3.05%	13.83	9.64	1.301	66.50
0.113	4.52%	48.86	0.028	3.16%	13.83	9.97	1.325	68.74
0.115	4.60%	47.91	0.028	3.16%	13.83	9.77	1.311	67.40
0.117	4.68%	49.17	0.028	3.16%	13.83	10.03	1.329	69.18
0.12	4.80%	49.01	0.028	3.16%	13.83	10.00	1.327	68.95
0.122	4.88%	49.65	0.028	3.16%	13.83	10.13	1.336	69.85
0.125	5.00%	49.65	0.028	3.16%	13.83	10.13	1.336	69.85
0.127	5.08%	49.49	0.028	3.16%	13.83	10.10	1.334	69.63
0.129	5.16%	50.28	0.028	3.16%	13.83	10.26	1.345	70.74
0.141	5.64%	50.59	0.029	3.28%	13.83	10.32	1.35	71.17
0.144	5.76%	51.23	0.029	3.28%	13.83	10.45	1.359	72.08
0.165	6.60%	52.18	0.029	3.28%	13.83	10.64	1.373	73.41
0.167	6.68%	52.65	0.029	3.28%	13.83	10.74	1.38	74.07
0.17	6.80%	52.49	0.029	3.28%	13.83	10.71	1.378	73.85
0.172	6.88%	52.02	0.029	3.28%	13.83	10.61	1.371	73.19
0.214	8.56%	54.71	0.031	3.50%	13.83	11.16	1.411	76.97
0.216	8.64%	55.02	0.031	3.50%	13.83	11.22	1.415	77.41
0.219	8.76%	54.71	0.031	3.50%	13.83	11.16	1.411	76.97
0.222	8.88%	53.91	0.031	3.50%	13.83	11.00	1.399	75.85
0.224	8.96%	54.71	0.031	3.50%	13.83	11.16	1.411	76.97
0.226	9.04%	54.71	0.031	3.50%	13.83	11.16	1.411	76.97
0.228	9.12%	54.71	0.031	3.50%	13.83	11.16	1.411	76.97
0.23	9.20%	54.39	0.031	3.50%	13.83	11.10	1.406	76.52
0.233	9.32%	55.65	0.031	3.50%	13.83	11.35	1.425	78.29
0.247	9.88%	55.5	0.031	3.50%	13.83	11.32	1.422	78.08
0.25	10.00%	55.02	0.031	3.50%	13.83	11.22	1.415	77.41
0.25	10.00%	55.97	0.031	3.50%	13.83	11.42	1.429	78.74

Confining Pressure: 2 tsf = 214.51 kPa= 27.76 psi
 Initial Height : 0.85 in
 Height after consolidation : 0.78 in
 Initial Diameter: 2.5 in
 Initial Area: 4.91 (in^2)
 Volume: 3.83 (in^3) = 62.75 g/(cm^3)
 Mass of soil (wet): 125.52 g
 Moist unit weight: 2.00 g/(cm^3)
 Mass of soil (dry): 114.32 g
 Dry unit weight: 1.82 g/(cm^3)
 Strain rate: 0.01 in/min

HORIZONTAL DISPLACEMENT (in)	% HORIZONTAL DISPLACEMENT (%)	HORIZONTAL FORCE (lb)	VERTICAL DISPLACEMENT (in)	% VERTICAL DISPLACEMENT (%)	VERTICAL STRESS (lb/in^2)	SHEAR STRESS (lb/in^2)	SHEAR/ VERTICAL	SHEAR STRESS (kPa)
0	0.00%	-1.17	0	0.00%	27.76	-0.24	-0.009	-1.66
0.001	0.04%	0.89	0	0.00%	27.76	0.18	0.006	1.24
0.012	0.48%	17.8	0.002	0.26%	27.76	3.63	0.131	25.03
0.014	0.56%	20.81	0.003	0.38%	27.76	4.24	0.153	29.24
0.017	0.68%	23.34	0.004	0.51%	27.76	4.75	0.171	32.76
0.019	0.76%	25.87	0.004	0.51%	27.76	5.27	0.19	36.34
0.021	0.84%	27.29	0.005	0.64%	27.76	5.56	0.2	38.34
0.024	0.96%	30.13	0.005	0.64%	27.76	6.14	0.221	42.34
0.043	1.72%	46.73	0.01	1.28%	27.76	9.52	0.343	65.66
0.045	1.80%	48.32	0.01	1.28%	27.76	9.84	0.355	67.86
0.047	1.88%	50.05	0.011	1.41%	27.76	10.2	0.367	70.34
0.049	1.96%	51	0.011	1.41%	27.76	10.39	0.374	71.66
0.052	2.08%	51.79	0.012	1.54%	27.76	10.55	0.38	72.76
0.054	2.16%	53.37	0.012	1.54%	27.76	10.87	0.392	74.97
0.057	2.28%	55.11	0.013	1.67%	27.76	11.23	0.404	77.45
0.059	2.36%	56.06	0.013	1.67%	27.76	11.42	0.411	78.76
0.061	2.44%	57.8	0.013	1.67%	27.76	11.78	0.424	81.24
0.085	3.40%	65.86	0.017	2.18%	27.76	13.42	0.483	92.55
0.087	3.48%	66.65	0.017	2.18%	27.76	13.58	0.489	93.66
0.09	3.60%	67.45	0.017	2.18%	27.76	13.74	0.495	94.76
0.092	3.68%	68.39	0.017	2.18%	27.76	13.93	0.502	96.07
0.095	3.80%	68.55	0.018	2.31%	27.76	13.97	0.503	96.34
0.097	3.88%	68.55	0.018	2.31%	27.76	13.97	0.503	96.34
0.099	3.96%	69.5	0.018	2.31%	27.76	14.16	0.51	97.66
0.102	4.08%	69.5	0.018	2.31%	27.76	14.16	0.51	97.66
0.104	4.16%	70.29	0.019	2.44%	27.76	14.32	0.516	98.76
0.107	4.28%	71.24	0.019	2.44%	27.76	14.51	0.523	100.07
0.109	4.36%	71.24	0.019	2.44%	27.76	14.51	0.523	100.07
0.112	4.48%	71.24	0.019	2.44%	27.76	14.51	0.523	100.07
0.114	4.56%	72.66	0.019	2.44%	27.76	14.8	0.533	102.07
0.116	4.64%	73.14	0.019	2.44%	27.76	14.9	0.537	102.76
0.119	4.76%	72.98	0.02	2.56%	27.76	14.87	0.536	102.55
0.121	4.84%	73.61	0.02	2.56%	27.76	15	0.54	103.45
0.123	4.92%	73.93	0.02	2.56%	27.76	15.06	0.543	103.86
0.126	5.04%	74.56	0.02	2.56%	27.76	15.19	0.547	104.76
0.128	5.12%	74.72	0.02	2.56%	27.76	15.22	0.548	104.97
0.13	5.20%	74.88	0.02	2.56%	27.76	15.25	0.55	105.17
0.157	6.28%	76.93	0.021	2.69%	27.76	15.67	0.565	108.07
0.159	6.36%	78.67	0.021	2.69%	27.76	16.03	0.577	110.55
0.162	6.48%	78.67	0.021	2.69%	27.76	16.03	0.577	110.55
0.164	6.56%	79.14	0.022	2.82%	27.76	16.12	0.581	111.17
0.192	7.68%	79.14	0.022	2.82%	27.76	16.12	0.581	111.17
0.195	7.80%	80.88	0.022	2.82%	27.76	16.48	0.594	113.66
0.228	9.12%	82.62	0.022	2.82%	27.76	16.83	0.606	116.07
0.23	9.20%	82.78	0.022	2.82%	27.76	16.86	0.608	116.28
0.233	9.32%	81.83	0.022	2.82%	27.76	16.67	0.601	114.97
0.235	9.40%	82.78	0.022	2.82%	27.76	16.86	0.608	116.28
0.249	9.96%	83.26	0.022	2.82%	27.76	16.96	0.611	116.97
0.25	10.00%	83.1	0.022	2.82%	27.76	16.93	0.61	116.76

Confining Pressure: 3 tsf = 321.76 kPa= 41.68 psi
 Initial Height : 0.970 in
 Height after consolidation : 0.943 in
 Initial Diameter: 2.5 in
 Initial Area: 4.91 (in²)
 Volume: 4.63 (in³) = 75.85 g/(cm³)
 Mass of soil (wet): 149.42 g
 Moist unit weight: 1.97 g/(cm³)
 Mass of soil (dry): 135.60 g
 Dry unit weight: 1.79 g/(cm³)
 Strain rate: 0.01 in/min

HORIZONTAL DISPLACEMENT (in)	% HORIZONTAL DISPLACEMENT (%)	HORIZONTAL FORCE (lb)	VERTICAL DISPLACEMENT (in)	% VERTICAL DISPLACEMENT (%)	VERTICAL STRESS (lb/in ²)	SHEAR STRESS (lb/in ²)	SHEAR/ VERTICAL	SHEAR STRESS (kPa)
0	0.00%	3.89	0	0.00%	41.68	0.79	0.019	5.45
0.011	0.44%	42.62	0.002	0.21%	41.68	8.68	0.208	59.86
0.013	0.52%	49.42	0.003	0.32%	41.68	10.07	0.242	69.45
0.015	0.60%	53.22	0.004	0.42%	41.68	10.84	0.26	74.76
0.017	0.68%	59.38	0.005	0.53%	41.68	12.1	0.29	83.45
0.02	0.80%	65.07	0.005	0.53%	41.68	13.26	0.318	91.45
0.022	0.88%	69.18	0.006	0.64%	41.68	14.09	0.338	97.17
0.024	0.96%	72.03	0.007	0.74%	41.68	14.67	0.352	101.17
0.026	1.04%	77.09	0.007	0.74%	41.68	15.7	0.377	108.28
0.044	1.76%	98.43	0.011	1.17%	41.68	20.05	0.481	138.28
0.046	1.84%	99.22	0.012	1.27%	41.68	20.21	0.485	139.38
0.049	1.96%	100.65	0.012	1.27%	41.68	20.5	0.492	141.38
0.051	2.04%	100.8	0.012	1.27%	41.68	20.54	0.493	141.66
0.053	2.12%	104.92	0.013	1.38%	41.68	21.37	0.513	147.38
0.056	2.24%	105.86	0.013	1.38%	41.68	21.57	0.517	148.76
0.058	2.32%	106.5	0.013	1.38%	41.68	21.7	0.521	149.66
0.06	2.40%	109.18	0.013	1.38%	41.68	22.24	0.534	153.38
0.063	2.52%	110.76	0.014	1.48%	41.68	22.56	0.541	155.59
0.065	2.60%	112.66	0.014	1.48%	41.68	22.95	0.551	158.28
0.079	3.16%	118.83	0.015	1.59%	41.68	24.21	0.581	166.97
0.081	3.24%	119.78	0.015	1.59%	41.68	24.4	0.585	168.28
0.084	3.36%	121.52	0.016	1.70%	41.68	24.75	0.594	170.69
0.086	3.44%	122.62	0.016	1.70%	41.68	24.98	0.599	172.28
0.089	3.56%	122.31	0.016	1.70%	41.68	24.92	0.598	171.86
0.091	3.64%	123.41	0.016	1.70%	41.68	25.14	0.603	173.38
0.093	3.72%	123.89	0.016	1.70%	41.68	25.24	0.606	174.07
0.115	4.60%	128.95	0.017	1.80%	41.68	26.27	0.63	181.17
0.117	4.68%	129.1	0.017	1.80%	41.68	26.3	0.631	181.38
0.12	4.80%	129.74	0.017	1.80%	41.68	26.43	0.634	182.28
0.122	4.88%	129.42	0.017	1.80%	41.68	26.37	0.633	181.86
0.124	4.96%	130.53	0.017	1.80%	41.68	26.59	0.638	183.38
0.138	5.52%	133.37	0.018	1.91%	41.68	27.17	0.652	187.38
0.17	6.80%	137.17	0.018	1.91%	41.68	27.94	0.67	192.69
0.172	6.88%	138.43	0.018	1.91%	41.68	28.2	0.677	194.48
0.174	6.96%	137.48	0.018	1.91%	41.68	28.01	0.672	193.17
0.177	7.08%	137.64	0.018	1.91%	41.68	28.04	0.673	193.38
0.179	7.16%	138.12	0.018	1.91%	41.68	28.14	0.675	194.07
0.201	8.04%	138.27	0.018	1.91%	41.68	28.17	0.676	194.28
0.203	8.12%	139.22	0.018	1.91%	41.68	28.36	0.68	195.59
0.206	8.24%	140.33	0.018	1.91%	41.68	28.59	0.686	197.17
0.208	8.32%	140.33	0.018	1.91%	41.68	28.59	0.686	197.17
0.211	8.44%	139.86	0.018	1.91%	41.68	28.49	0.684	196.48
0.222	8.88%	140.01	0.018	1.91%	41.68	28.52	0.684	196.69
0.225	9.00%	140.96	0.018	1.91%	41.68	28.72	0.689	198.07
0.227	9.08%	140.65	0.018	1.91%	41.68	28.65	0.687	197.59
0.232	9.28%	140.17	0.017	1.80%	41.68	28.56	0.685	196.97
0.234	9.36%	140.49	0.017	1.80%	41.68	28.62	0.687	197.38
0.236	9.44%	140.49	0.017	1.80%	41.68	28.62	0.687	197.38
0.25	10.00%	140.33	0.017	1.80%	41.68	28.59	0.686	197.17

Direct Shear Test - SPT 1 - 3.5 feet

Modified Mohr-Coulomb Spt1- 3.5 feet

Wed Nov 20, 1996

DIRECT SHEAR TEST DATA

Project: Plasma Torch Demo

Test No.: 3

Boring No.: SPT1

Sample No.: 3

Depth: 5.5 feet

Location: Savannah River Site

Sample Type: Remolded sandy soil

Tested by: Kim Finke

Moisture Content: 12.30 %

Confining Pressure:

1 tsf=

107.25 kPa=

13.83 psi

Initial Height:

0.97 in

Height after consolidation:

0.93 in

Initial Diameter:

2.5 in

Initial Area:

4.91 in²

Volume:

4.57 in³=

74.80 (cm³)

Mass of Soil (wet):

146.14 g

Moist unit weight:

1.95 g/(cm³)

Mass of soil (dry):

131.6 g

Dry unit weight:

1.76 g/(cm³)

Strain rate:

0.01 in/min

HORIZONTAL DISPLACEMENT (in)	%HORIZONTAL DISPLACEMENT (%)	HORIZONTAL FORCE (lb)	VERTICAL DISPLACEMENT (in)	%VERTICAL DISPLACEMENT (%)	NORMAL STRESS (lb/in ²)	SHEAR STRESS (lb/in ²)	SHEAR/ VERTICAL	SHEAR STRESS (kPa)
0	0.00%	-2.59	0	0.00%	13.87	-0.53	-0.038	-3.66
0.018	0.72%	22.39	0.004	0.43%	13.87	4.56	0.329	31.45
0.02	0.80%	24.92	0.005	0.54%	13.87	5.08	0.366	35.03
0.023	0.92%	28.08	0.006	0.65%	13.87	5.72	0.412	39.45
0.025	1.00%	31.87	0.006	0.65%	13.87	6.49	0.468	44.76
0.028	1.12%	33.45	0.007	0.75%	13.87	6.82	0.491	47.03
0.03	1.20%	35.19	0.008	0.86%	13.87	7.17	0.517	49.45
0.032	1.28%	36.93	0.008	0.86%	13.87	7.52	0.542	51.86
0.034	1.36%	40.09	0.008	0.86%	13.87	8.17	0.589	56.34
0.036	1.44%	42.31	0.008	0.86%	13.87	8.62	0.621	59.45
0.038	1.52%	44.68	0.009	0.97%	13.87	9.1	0.656	62.76
0.041	1.64%	45.15	0.009	0.97%	13.87	9.2	0.663	63.45
0.054	2.16%	53.22	0.009	0.97%	13.87	10.84	0.782	74.76
0.057	2.28%	54.01	0.009	0.97%	13.87	11	0.793	75.86
0.059	2.36%	54.48	0.009	0.97%	13.87	11.1	0.8	76.55
0.061	2.44%	54.8	0.009	0.97%	13.87	11.16	0.805	76.97
0.063	2.52%	55.27	0.009	0.97%	13.87	11.26	0.812	77.66
0.066	2.64%	55.59	0.009	0.97%	13.87	11.32	0.816	78.07
0.068	2.72%	56.54	0.009	0.97%	13.87	11.52	0.83	79.45
0.071	2.84%	56.22	0.008	0.86%	13.87	11.45	0.826	78.97
0.116	4.64%	52.74	0.005	0.54%	13.87	10.74	0.775	74.07
0.119	4.76%	52.27	0.005	0.54%	13.87	10.65	0.768	73.45
0.121	4.84%	52.11	0.005	0.54%	13.87	10.62	0.765	73.24
0.124	4.96%	52.11	0.005	0.54%	13.87	10.62	0.765	73.24
0.126	5.04%	52.11	0.005	0.54%	13.87	10.62	0.765	73.24
0.128	5.12%	51.79	0.005	0.54%	13.87	10.55	0.761	72.76
0.153	6.12%	50.05	0.004	0.43%	13.87	10.2	0.735	70.34
0.155	6.20%	50.21	0.004	0.43%	13.87	10.23	0.737	70.55
0.157	6.28%	49.74	0.004	0.43%	13.87	10.13	0.731	69.86
0.168	6.72%	50.05	0.004	0.43%	13.87	10.2	0.735	70.34
0.205	8.20%	48.79	0.003	0.32%	13.87	9.94	0.717	68.55
0.242	9.68%	48.79	0.002	0.22%	13.87	9.94	0.717	68.55
0.245	9.80%	48.63	0.002	0.22%	13.87	9.91	0.714	68.34
0.247	9.88%	48.79	0.002	0.22%	13.87	9.94	0.717	68.55
0.25	10.00%	48.63	0.002	0.22%	13.87	9.91	0.714	68.34
0.25	10.00%	48.63	0.002	0.22%	13.87	9.91	0.714	68.34

Confining Pressure:	2 tsf=	214.5 kPa=	27.66 psi
Initial Height:	0.81 in		
Height after consolidation:	0.625 in		
Initial Diameter:	2.5 in		
Initial Area:	4.91 in ²		
Volume:	3.07 in ³ =	50.27 (cm ³)	
Mass of Soil (wet):	123.01 g		
Moist unit weight:	2.45 g/(cm ³)		
Mass of soil (dry):	112 g		
Dry unit weight:	2.23 g/(cm ³)		
Strain rate:	0.01 in/min		

HORIZONTAL DISPLACEMENT (in)	% HORIZONTAL DISPLACEMENT (%)	HORIZONTAL FORCE (lb)	VERTICAL DISPLACEMENT (in)	% VERTICAL DISPLACEMENT (%)	NORMAL STRESS (lb/in ²)	SHEAR STRESS (lb/in ²)	SHEAR/ VERTICAL	SHEAR STRESS (kPa)
0	0.00%	4.21	0	0.00%	27.76	0.86	0.031	5.93
0.01	0.40%	43.41	0.004	0.64%	27.76	8.84	0.319	60.97
0.012	0.48%	47.21	0.004	0.64%	27.76	9.62	0.346	66.34
0.014	0.56%	51.16	0.004	0.64%	27.76	10.42	0.375	71.86
0.017	0.68%	54.17	0.005	0.80%	27.76	11.03	0.397	76.07
0.018	0.72%	57.01	0.005	0.80%	27.76	11.61	0.418	80.07
0.02	0.80%	59.22	0.005	0.80%	27.76	12.07	0.435	83.24
0.022	0.88%	61.75	0.006	0.96%	27.76	12.58	0.453	86.76
0.024	0.96%	63.33	0.006	0.96%	27.76	12.9	0.465	88.97
0.027	1.08%	65.71	0.006	0.96%	27.76	13.39	0.482	92.34
0.041	1.64%	74.88	0.007	1.12%	27.76	15.25	0.549	105.17
0.043	1.72%	76.3	0.008	1.28%	27.76	15.54	0.56	107.17
0.045	1.80%	77.25	0.008	1.28%	27.76	15.74	0.567	108.55
0.048	1.92%	78.99	0.008	1.28%	27.76	16.09	0.58	110.97
0.078	3.12%	91.32	0.009	1.44%	27.76	18.6	0.67	128.28
0.094	3.76%	95.59	0.01	1.60%	27.76	19.47	0.701	134.28
0.096	3.84%	95.43	0.01	1.60%	27.76	19.44	0.7	134.07
0.099	3.96%	95.59	0.01	1.60%	27.76	19.47	0.701	134.28
0.101	4.04%	96.38	0.01	1.60%	27.76	19.63	0.707	135.38
0.103	4.12%	96.38	0.01	1.60%	27.76	19.63	0.707	135.38
0.106	4.24%	96.38	0.01	1.60%	27.76	19.63	0.707	135.38
0.109	4.36%	96.38	0.01	1.60%	27.76	19.63	0.707	135.38
0.111	4.44%	96.85	0.01	1.60%	27.76	19.73	0.711	136.07
0.113	4.52%	95.75	0.01	1.60%	27.76	19.51	0.703	134.55
0.115	4.60%	96.38	0.01	1.60%	27.76	19.63	0.707	135.38
0.137	5.48%	97.17	0.01	1.60%	27.76	19.79	0.713	136.48
0.139	5.56%	96.38	0.01	1.60%	27.76	19.63	0.707	135.38
0.141	5.64%	98.27	0.01	1.60%	27.76	20.02	0.721	138.07
0.144	5.76%	97.96	0.01	1.60%	27.76	19.96	0.719	137.66
0.147	5.88%	98.75	0.01	1.60%	27.76	20.12	0.725	138.76
0.15	6.00%	97.01	0.009	1.44%	27.76	19.76	0.712	136.28
0.152	6.08%	98.27	0.009	1.44%	27.76	20.02	0.721	138.07
0.154	6.16%	97.8	0.009	1.44%	27.76	19.92	0.718	137.38
0.155	6.20%	98.27	0.009	1.44%	27.76	20.02	0.721	138.07
0.178	7.12%	96.85	0.008	1.28%	27.76	19.73	0.711	136.07
0.18	7.20%	96.54	0.008	1.28%	27.76	19.67	0.708	135.66
0.183	7.32%	97.01	0.008	1.28%	27.76	19.76	0.712	136.28
0.186	7.44%	96.38	0.008	1.28%	27.76	19.63	0.707	135.38
0.188	7.52%	97.33	0.008	1.28%	27.76	19.83	0.714	136.76
0.2	8.00%	97.01	0.008	1.28%	27.76	19.76	0.712	136.28
0.202	8.08%	97.48	0.008	1.28%	27.76	19.86	0.715	136.97
0.205	8.20%	96.38	0.008	1.28%	27.76	19.63	0.707	135.38
0.207	8.28%	97.33	0.008	1.28%	27.76	19.83	0.714	136.76
0.209	8.36%	96.85	0.008	1.28%	27.76	19.73	0.711	136.07
0.228	9.12%	95.11	0.007	1.12%	27.76	19.38	0.698	133.66
0.23	9.20%	95.27	0.007	1.12%	27.76	19.41	0.699	133.86
0.233	9.32%	95.43	0.007	1.12%	27.76	19.44	0.7	134.07
0.249	9.96%	95.9	0.007	1.12%	27.76	19.54	0.704	134.76
0.25	10.00%	95.9	0.007	1.12%	27.76	19.54	0.704	134.76

Confining Pressure: 3 tsf= 321.75 kPa= 41.49 psi
 Initial Height: 0.76 in
 Height after consolidation: 0.604 in
 Initial Diameter: 2.5 in
 Initial Area: 4.91 in²
 Volume: 2.97 in³= 48.58 (cm³)
 Mass of Soil (wet): 137.53 g
 Moist unit weight: 2.83 g/(cm³)
 Mass of soil (dry): 115.47 g
 Dry unit weight: 2.38 g/(cm³)
 Strain rate: 0.01 in/min

HORIZONTAL DISPLACEMENT (in)	% HORIZONTAL DISPLACEMENT (%)	HORIZONTAL FORCE (lb)	VERTICAL DISPLACEMENT (in)	% VERTICAL DISPLACEMENT (%)	NORMAL STRESS (lb/in ²)	SHEAR STRESS (lb/in ²)	SHEAR/ VERTICAL	SHEAR STRESS (kPa)
0	0.00%	0.57	0	0.00%	41.71	0.12	0.003	0.83
0.013	0.52%	55.43	0.003	0.50%	41.71	11.29	0.271	77.86
0.015	0.60%	59.22	0.003	0.50%	41.71	12.07	0.289	83.24
0.017	0.68%	59.38	0.003	0.50%	41.71	12.1	0.29	83.45
0.02	0.80%	61.6	0.004	0.66%	41.71	12.55	0.301	86.55
0.023	0.92%	64.28	0.004	0.66%	41.71	13.1	0.314	90.34
0.025	1.00%	68.24	0.004	0.66%	41.71	13.9	0.333	95.86
0.027	1.08%	70.77	0.004	0.66%	41.71	14.42	0.346	99.45
0.041	1.64%	76.77	0.005	0.83%	41.71	15.64	0.375	107.86
0.043	1.72%	77.41	0.005	0.83%	41.71	15.77	0.378	108.76
0.045	1.80%	81.04	0.005	0.83%	41.71	16.51	0.396	113.86
0.048	1.92%	83.1	0.005	0.83%	41.71	16.93	0.406	116.76
0.05	2.00%	81.52	0.006	0.99%	41.71	16.61	0.398	114.55
0.052	2.08%	82.15	0.006	0.99%	41.71	16.74	0.401	115.45
0.054	2.16%	81.52	0.006	0.99%	41.71	16.61	0.398	114.55
0.073	2.92%	86.1	0.007	1.16%	41.71	17.54	0.421	120.97
0.075	3.00%	87.52	0.007	1.16%	41.71	17.83	0.428	122.97
0.078	3.12%	85.47	0.007	1.16%	41.71	17.41	0.417	120.07
0.08	3.20%	85.63	0.007	1.16%	41.71	17.44	0.418	120.28
0.082	3.28%	85.94	0.007	1.16%	41.71	17.51	0.42	120.76
0.084	3.36%	88.16	0.007	1.16%	41.71	17.96	0.431	123.86
0.086	3.44%	88.31	0.008	1.32%	41.71	17.99	0.431	124.07
0.089	3.56%	91.32	0.008	1.32%	41.71	18.6	0.446	128.28
0.091	3.64%	92.27	0.008	1.32%	41.71	18.8	0.451	129.66
0.11	4.40%	93.85	0.009	1.49%	41.71	19.12	0.458	131.86
0.122	4.88%	96.38	0.009	1.49%	41.71	19.63	0.471	135.38
0.124	4.96%	97.01	0.009	1.49%	41.71	19.76	0.474	136.28
0.127	5.08%	95.75	0.009	1.49%	41.71	19.51	0.468	134.55
0.13	5.20%	82.78	0.017	2.81%	41.71	16.86	0.404	116.28
0.131	5.24%	93.69	0.021	3.48%	41.71	19.09	0.458	131.66
0.148	5.92%	110.61	0.033	5.46%	41.71	22.53	0.54	155.38
0.15	6.00%	115.03	0.034	5.63%	41.71	23.43	0.562	161.59
0.153	6.12%	118.2	0.035	5.79%	41.71	24.08	0.577	166.07
0.167	6.68%	128.16	0.038	6.29%	41.71	26.11	0.626	180.07
0.187	7.48%	139.22	0.041	6.79%	41.71	28.36	0.68	195.59
0.189	7.56%	140.17	0.042	6.95%	41.71	28.56	0.685	196.97
0.192	7.68%	140.8	0.042	6.95%	41.71	28.68	0.688	197.79
0.195	7.80%	141.44	0.042	6.95%	41.71	28.81	0.691	198.69
0.197	7.88%	142.07	0.043	7.12%	41.71	28.94	0.694	199.59
0.199	7.96%	143.18	0.043	7.12%	41.71	29.17	0.699	201.17
0.202	8.08%	144.12	0.043	7.12%	41.71	29.36	0.704	202.48
0.204	8.16%	144.44	0.044	7.28%	41.71	29.43	0.706	202.97
0.206	8.24%	144.12	0.044	7.28%	41.71	29.36	0.704	202.48
0.208	8.32%	145.55	0.044	7.28%	41.71	29.65	0.711	204.48
0.213	8.52%	146.02	0.044	7.28%	41.71	29.75	0.713	205.17
0.215	8.60%	146.81	0.044	7.28%	41.71	29.91	0.717	206.28
0.234	9.36%	145.7	0.046	7.62%	41.71	29.68	0.712	204.69
0.25	10.00%	144.91	0.046	7.62%	41.71	29.52	0.708	203.59
0.25	10.00%	144.44	0.046	7.62%	41.71	29.43	0.706	202.97

Direct Shear Test - SPT 1 - 5.5 feet

Modified Mohr-Coulomb for DSS of SPT1- 5.5 feet

Tue Nov 26, 1996

DIRECT SHEAR TEST DATA

Project: Plasma Torch Demo
 Test No.: 4
 Boring No.: SPT1
 Sample No.: 4
 Depth: 7.5 feet

Location: Savannah River Site
 Sample Type: Remolded sandy soil
 Tested by: Kimberly Finke
 Moisture content: 16.64 %

Confining Pressure:	1 tsf=	107.25 kPa=	13.83 psi
Initial Height:	0.85 in		
Height after consolidation:	0.82 in		
Initial Diameter:	2.5 in		
Initial Area:	4.91 in ²		
Volume:	4.03 in ³ =	65.91 cm ³	
Mass of soil(wet):	131 g		
Moist unit weight:	1.99 g/(cm ³)		
Mass of soil(dry):	116.69 g		
Dry unit weight:	1.77 g/(cm ³)		
Strain rate:	0.01 in/min		

HORIZONTAL DISPLACEMENT (in)	% HORIZONTAL DISPLACEMENT (%)	HORIZONTAL FORCE (lb)	VERTICAL DISPLACEMENT (in)	% VERTICAL DISPLACEMENT (%)	NORMAL STRESS (lb/in ²)	SHEAR STRESS (lb/in ²)	SHEAR/ VERTICAL	SHEAR STRESS (kPa)
0	0.00%	-1.01	0	0.00%	13.84	-0.21	-0.015	-1.45
0.018	0.72%	24.92	0.003	0.37%	13.84	5.08	0.367	35.03
0.021	0.84%	26.81	0.003	0.37%	13.84	5.46	0.395	37.66
0.023	0.92%	27.13	0.003	0.37%	13.84	5.53	0.399	38.14
0.025	1.00%	28.71	0.004	0.49%	13.84	5.85	0.423	40.34
0.028	1.12%	30.45	0.004	0.49%	13.84	6.2	0.448	42.76
0.03	1.20%	31.87	0.004	0.49%	13.84	6.49	0.469	44.76
0.032	1.28%	32.66	0.005	0.61%	13.84	6.65	0.481	45.86
0.035	1.40%	32.98	0.005	0.61%	13.84	6.72	0.485	46.34
0.037	1.48%	35.35	0.005	0.61%	13.84	7.2	0.52	49.66
0.039	1.56%	36.3	0.005	0.61%	13.84	7.39	0.534	50.97
0.041	1.64%	36.93	0.006	0.73%	13.84	7.52	0.544	51.86
0.044	1.76%	39.46	0.006	0.73%	13.84	8.04	0.581	55.45
0.046	1.84%	39.15	0.006	0.73%	13.84	7.97	0.576	54.97
0.048	1.92%	39.78	0.006	0.73%	13.84	8.1	0.586	55.86
0.074	2.96%	48.95	0.009	1.10%	13.84	9.97	0.721	68.76
0.076	3.04%	48.95	0.009	1.10%	13.84	9.97	0.721	68.76
0.079	3.16%	49.42	0.009	1.10%	13.84	10.07	0.728	69.45
0.081	3.24%	49.74	0.009	1.10%	13.84	10.13	0.732	69.86
0.084	3.36%	50.21	0.009	1.10%	13.84	10.23	0.739	70.55
0.086	3.44%	51	0.009	1.10%	13.84	10.39	0.751	71.66
0.088	3.52%	51	0.009	1.10%	13.84	10.39	0.751	71.66
0.142	5.68%	54.32	0.011	1.34%	13.84	11.07	0.8	76.34
0.145	5.80%	55.9	0.011	1.34%	13.84	11.39	0.823	78.55
0.147	5.88%	55.27	0.011	1.34%	13.84	11.26	0.814	77.66
0.149	5.96%	55.9	0.011	1.34%	13.84	11.39	0.823	78.55
0.152	6.08%	55.11	0.011	1.34%	13.84	11.23	0.811	77.45
0.188	7.52%	54.01	0.009	1.10%	13.84	11	0.795	75.86
0.19	7.60%	53.37	0.009	1.10%	13.84	10.87	0.786	74.97
0.193	7.72%	54.01	0.009	1.10%	13.84	11	0.795	75.86
0.195	7.80%	53.85	0.009	1.10%	13.84	10.97	0.793	75.66
0.197	7.88%	53.85	0.009	1.10%	13.84	10.97	0.793	75.66
0.2	8.00%	54.01	0.009	1.10%	13.84	11	0.795	75.86
0.202	8.08%	53.69	0.009	1.10%	13.84	10.94	0.79	75.45
0.205	8.20%	53.53	0.009	1.10%	13.84	10.91	0.788	75.24
0.246	9.84%	51.95	0.009	1.10%	13.84	10.58	0.765	72.97
0.249	9.96%	51.64	0.009	1.10%	13.84	10.52	0.76	72.55
0.25	10.00%	51.64	0.009	1.10%	13.84	10.52	0.76	72.55

Confining Pressure:	2 tsf=	214.5 kPa=	27.66 psi
Initial Height:	0.98 in		
Height after consolidation:	0.943 in		
Initial Diameter:	2.5 in		
Initial Area:	4.91 in ²		
Volume:	4.63 in ³ =	75.80 cm ³	
Mass of soil(wet):	146.79 g		
Moist unit weight:	1.94 g/(cm ³)		
Mass of soil(dry):	131.69 g		
Dry unit weight:	1.74 g/(cm ³)		
Strain rate:	0.01 in/min		

HORIZONTAL DISPLACEMENT (in)	% HORIZONTAL DISPLACEMENT (%)	HORIZONTAL FORCE (lb)	VERTICAL DISPLACEMENT (in)	% VERTICAL DISPLACEMENT (%)	NORMAL STRESS (lb/in ²)	SHEAR STRESS (lb/in ²)	SHEAR/ VERTICAL	SHEAR STRESS (kPa)
0	0.00%	7.53	0	0.00%	27.74	1.53	0.055	
0.017	0.68%	56.69	0.003	0.32%	27.74	11.55	0.416	79.66
0.019	0.76%	60.33	0.004	0.42%	27.74	12.29	0.443	84.76
0.021	0.84%	64.92	0.004	0.42%	27.74	13.22	0.477	91.17
0.023	0.92%	68.87	0.004	0.42%	27.74	14.03	0.506	96.76
0.025	1.00%	73.3	0.005	0.53%	27.74	14.93	0.538	102.97
0.027	1.08%	74.72	0.005	0.53%	27.74	15.22	0.549	104.97
0.03	1.20%	76.14	0.005	0.53%	27.74	15.51	0.559	106.97
0.032	1.28%	78.35	0.005	0.53%	27.74	15.96	0.575	110.07
0.034	1.36%	79.94	0.005	0.53%	27.74	16.28	0.587	112.28
0.037	1.48%	81.83	0.005	0.53%	27.74	16.67	0.601	114.97
0.038	1.52%	84.68	0.005	0.53%	27.74	17.25	0.622	118.97
0.056	2.24%	91.95	0.006	0.64%	27.74	18.73	0.675	129.17
0.058	2.32%	90.69	0.006	0.64%	27.74	18.47	0.666	127.38
0.06	2.40%	93.06	0.006	0.64%	27.74	18.96	0.683	130.76
0.063	2.52%	94.16	0.006	0.64%	27.74	19.18	0.692	132.28
0.065	2.60%	95.9	0.006	0.64%	27.74	19.54	0.704	134.76
0.067	2.68%	95.11	0.006	0.64%	27.74	19.38	0.698	133.66
0.07	2.80%	97.17	0.006	0.64%	27.74	19.79	0.714	136.48
0.086	3.44%	100.49	0.005	0.53%	27.74	20.47	0.738	141.17
0.088	3.52%	100.65	0.004	0.42%	27.74	20.5	0.739	141.38
0.091	3.64%	101.12	0.004	0.42%	27.74	20.6	0.743	142.07
0.093	3.72%	101.12	0.004	0.42%	27.74	20.6	0.743	142.07
0.095	3.80%	100.49	0.004	0.42%	27.74	20.47	0.738	141.17
0.097	3.88%	100.96	0.004	0.42%	27.74	20.57	0.741	141.86
0.1	4.00%	100.49	0.004	0.42%	27.74	20.47	0.738	141.17
0.102	4.08%	100.65	0.003	0.32%	27.74	20.5	0.739	141.38
0.104	4.16%	100.33	0.003	0.32%	27.74	20.44	0.737	140.97
0.126	5.04%	98.27	0.002	0.21%	27.74	20.02	0.722	138.07
0.128	5.12%	97.96	0.002	0.21%	27.74	19.96	0.719	137.66
0.13	5.20%	97.33	0.002	0.21%	27.74	19.83	0.715	136.76
0.133	5.32%	97.8	0.002	0.21%	27.74	19.92	0.718	137.38
0.135	5.40%	98.12	0.002	0.21%	27.74	19.99	0.721	137.86
0.138	5.52%	97.17	0.002	0.21%	27.74	19.79	0.714	136.48
0.176	7.04%	93.69	0.002	0.21%	27.74	19.09	0.688	131.66
0.179	7.16%	92.9	0.002	0.21%	27.74	18.93	0.682	130.55
0.181	7.24%	94.32	0.002	0.21%	27.74	19.22	0.693	132.55
0.184	7.36%	93.53	0.002	0.21%	27.74	19.05	0.687	131.38
0.186	7.44%	93.69	0.002	0.21%	27.74	19.09	0.688	131.66
0.188	7.52%	92.43	0.002	0.21%	27.74	18.83	0.679	129.86
0.222	8.88%	92.74	0.002	0.21%	27.74	18.89	0.681	130.28
0.224	8.96%	92.9	0.002	0.21%	27.74	18.93	0.682	130.55
0.226	9.04%	93.37	0.002	0.21%	27.74	19.02	0.686	131.17
0.228	9.12%	92.58	0.002	0.21%	27.74	18.86	0.68	130.07
0.231	9.24%	93.06	0.002	0.21%	27.74	18.96	0.683	130.76
0.233	9.32%	92.74	0.002	0.21%	27.74	18.89	0.681	130.28
0.235	9.40%	93.69	0.002	0.21%	27.74	19.09	0.688	131.66
0.238	9.52%	93.85	0.002	0.21%	27.74	19.12	0.689	131.86
0.25	10.00%	94.32	0.002	0.21%	27.74	19.22	0.693	132.55

Confining Pressure:	3 tsf=	321.75 kPa=	41.49 psi
Initial Height:	0.92 in		
Height after consolidation:	0.84 in		
Initial Diameter:	2.5 in		
Initial Area:	4.91 in ²		
Volume:	4.12 in ³ =	67.52 cm ³	
Mass of soil(wet):	148.1 g		
Moist unit weight:	2.19 g/(cm ³)		
Mass of soil(dry):	130.63 g		
Dry unit weight:	1.93 g/(cm ³)		
Strain rate:	0.01 in/min		

HORIZONTAL DISPLACEMENT (in)	% HORIZONTAL DISPLACEMENT (%)	HORIZONTAL FORCE (lb)	VERTICAL DISPLACEMENT (in)	% VERTICAL DISPLACEMENT (%)	VERTICAL STRESS (lb/in ²)	SHEAR STRESS (lb/in ²)	SHEAR/ VERTICAL	SHEAR STRESS (kPa)
0	0.00%	-1.64	0	0.00%	41.59	-0.33	-0.008	-2.28
0.017	0.68%	68.55	0.003	0.36%	41.59	13.97	0.336	96.34
0.019	0.76%	75.51	0.004	0.48%	41.59	15.38	0.37	106.07
0.021	0.84%	81.04	0.004	0.48%	41.59	16.51	0.397	113.86
0.023	0.92%	86.58	0.004	0.48%	41.59	17.64	0.424	121.66
0.025	1.00%	90.05	0.004	0.48%	41.59	18.35	0.441	126.55
0.028	1.12%	93.06	0.005	0.60%	41.59	18.96	0.456	130.76
0.029	1.16%	96.54	0.005	0.60%	41.59	19.67	0.473	135.66
0.031	1.24%	100.8	0.005	0.60%	41.59	20.54	0.494	141.66
0.033	1.32%	104.12	0.005	0.60%	41.59	21.21	0.51	146.28
0.036	1.44%	108.39	0.005	0.60%	41.59	22.08	0.531	152.28
0.039	1.56%	111.08	0.005	0.60%	41.59	22.63	0.544	156.07
0.065	2.60%	130.37	0.005	0.60%	41.59	26.56	0.639	183.17
0.067	2.68%	131.48	0.005	0.60%	41.59	26.78	0.644	184.69
0.07	2.80%	131.48	0.005	0.60%	41.59	26.78	0.644	184.69
0.072	2.88%	132.42	0.005	0.60%	41.59	26.98	0.649	186.07
0.074	2.96%	133.85	0.005	0.60%	41.59	27.27	0.656	188.07
0.077	3.08%	135.27	0.005	0.60%	41.59	27.56	0.663	190.07
0.079	3.16%	134.32	0.004	0.48%	41.59	27.36	0.658	188.69
0.081	3.24%	136.54	0.004	0.48%	41.59	27.81	0.669	191.79
0.084	3.36%	136.69	0.004	0.48%	41.59	27.85	0.67	192.07
0.086	3.44%	136.69	0.004	0.48%	41.59	27.85	0.67	192.07
0.114	4.56%	136.38	0.002	0.24%	41.59	27.78	0.668	191.59
0.117	4.68%	136.38	0.002	0.24%	41.59	27.78	0.668	191.59
0.119	4.76%	135.43	0.002	0.24%	41.59	27.59	0.663	190.28
0.122	4.88%	135.59	0.002	0.24%	41.59	27.62	0.664	190.48
0.124	4.96%	134.16	0.002	0.24%	41.59	27.33	0.657	188.48
0.126	5.04%	134.48	0.002	0.24%	41.59	27.4	0.659	188.97
0.128	5.12%	134.01	0.002	0.24%	41.59	27.3	0.656	188.28
0.131	5.24%	135.59	0.002	0.24%	41.59	27.62	0.664	190.48
0.133	5.32%	132.9	0.002	0.24%	41.59	27.07	0.651	186.69
0.148	5.92%	133.85	0.002	0.24%	41.59	27.27	0.656	188.07
0.15	6.00%	131.79	0.002	0.24%	41.59	26.85	0.646	185.17
0.153	6.12%	133.22	0.002	0.24%	41.59	27.14	0.653	187.17
0.155	6.20%	133.22	0.002	0.24%	41.59	27.14	0.653	187.17
0.157	6.28%	132.9	0.002	0.24%	41.59	27.07	0.651	186.69
0.16	6.40%	130.69	0.002	0.24%	41.59	26.62	0.64	183.59
0.201	8.04%	132.74	0.002	0.24%	41.59	27.04	0.65	186.48
0.203	8.12%	132.42	0.002	0.24%	41.59	26.98	0.649	186.07
0.206	8.24%	131.95	0.002	0.24%	41.59	26.88	0.646	185.38
0.208	8.32%	131.48	0.002	0.24%	41.59	26.78	0.644	184.69
0.21	8.40%	132.27	0.002	0.24%	41.59	26.95	0.648	185.86
0.212	8.48%	130.84	0.002	0.24%	41.59	26.66	0.641	183.86
0.215	8.60%	131.95	0.002	0.24%	41.59	26.88	0.646	185.38
0.241	9.64%	130.37	0.002	0.24%	41.59	26.56	0.639	183.17
0.243	9.72%	131.79	0.002	0.24%	41.59	26.85	0.646	185.17
0.246	9.84%	131.79	0.002	0.24%	41.59	26.85	0.646	185.17
0.248	9.92%	131	0.002	0.24%	41.59	26.69	0.642	184.07
0.25	10.00%	131.79	0.002	0.24%	41.59	26.85	0.646	185.17

Direct Shear Test - SPT1- 7.5 feet

Modified Mohr-Coulomb of SPT1- 7.5 feet

Appendix C

Ground Penetrating Radar Pre- and Post Melt Records

Conducted by GT Geosystems Engineering
South of K-Seepage Basin, Aiken, S.C.
Field Tests, September to December, 1996

PulseEKKO Data Sheet

DATA FILE #1 PARAMETERS:

Data File = c:\ekko\0_srs.hd

Savannah River Site

K Reactor Initial Site Characterization

26/09/96

NUMBER OF TRACES = 53
NUMBER OF PTS/TRC = 250
TIMEZERO AT POINT = 22
TOTAL TIME WINDOW = 200
STARTING POSITION = 0.0000
FINAL POSITION = 52.0000
STEP SIZE USED = 1.0000
POSITION UNITS = metres
NOMINAL FREQUENCY = 200.00
ANTENNA SEPARATION = 1.0000
PULSER VOLTAGE (V) = 400
NUMBER OF STACKS = 16
SURVEY MODE = Reflection

PROCESSING SELECTED:

Trace Stacking : 1
Points Stacking : 1
Trace Differencing: N
Gain Type : CONSTANT
Factor : 50.000
Selection : Time = all
Trace = 1 to 52

PLOT LAYOUT PARAMETERS:

Trace Spacing : 0.100"
Trace Width : 0.200"
Trace Position : 1.000" to 6.000"
Left/Right Margin : 0.500" / 0.000"
Border Size : 0.500"
Page Length/Width : 11.000" / 8.500"
Printer Name : HP LaserJet II 300dpi

LIVE ϕ
26 SEP 76

PulseEKKO Data Sheet

DATA FILE #1 PARAMETERS:

Data File = c:\ekko\6_srs.hd

Savannah River Site

K Reactor Initial Site Characterization

26/09/96

NUMBER OF TRACES = 52
NUMBER OF PTS/TRC = 250
TIMEZERO AT POINT = 20
TOTAL TIME WINDOW = 200
STARTING POSITION = 0.0000
FINAL POSITION = 51.0000
STEP SIZE USED = 1.0000
POSITION UNITS = metres
NOMINAL FREQUENCY = 200.00
ANTENNA SEPARATION = 1.0000
PULSER VOLTAGE (V) = 400
NUMBER OF STACKS = 16
SURVEY MODE = Reflection

PROCESSING SELECTED:

Trace Stacking : 1
Points Stacking : 1
Trace Differencing: N
Gain Type : CONSTANT
Factor : 50.000
Selection : Time = all
Trace = 1 to 52

PLOT LAYOUT PARAMETERS:

Trace Spacing : 0.100"
Trace Width : 0.200"
Trace Position : 1.000" to 6.000"
Left/Right Margin : 0.500" / 0.000"
Border Size : 0.500"
Page Length/Width : 11.000" / 8.500"
Printer Name : HP LaserJet II 300dpi

PulseEKKO Data Sheet

DATA FILE #1 PARAMETERS:

Data File = c:\ekko\12_srs.hd

Savannah River Site

K Reactor Initial Site Characterization

26/09/96

NUMBER OF TRACES = 52
NUMBER OF PTS/TRC = 250
TIMEZERO AT POINT = 14
TOTAL TIME WINDOW = 200
STARTING POSITION = 0.0000
FINAL POSITION = 51.0000
STEP SIZE USED = 1.0000
POSITION UNITS = metres
NOMINAL FREQUENCY = 200.00
ANTENNA SEPARATION = 1.0000
PULSER VOLTAGE (V) = 400
NUMBER OF STACKS = 16
SURVEY MODE = Reflection

PROCESSING SELECTED:

Trace Stacking : 1
Points Stacking : 1
Trace Differencing: N
Gain Type : CONSTANT
Factor : 50.000
Selection : Time = all
Trace = 1 to 52

PLOT LAYOUT PARAMETERS:

Trace Spacing : 0.100"
Trace Width : 0.200"
Trace Position : 1.000" to 6.000"
Left/Right Margin : 0.500" / 0.000"
Border Size : 0.500"
Page Length/Width : 11.000" / 8.500"
Printer Name : HP LaserJet II 300dpi

PulseEKKO Data Sheet

DATA FILE #1 PARAMETERS:

Data File = c:\ekko\47_srs.hd

Savannah River Site

K Reactor Initial Site Characterization

12/09/96

NUMBER OF TRACES = 52
NUMBER OF PTS/TRC = 312
TIMEZERO AT POINT = 20
TOTAL TIME WINDOW = 250
STARTING POSITION = 0.000000
FINAL POSITION = 51.000000
STEP SIZE USED = 1.000000
POSITION UNITS = metres
NOMINAL FREQUENCY = 200.000000
ANTENNA SEPARATION = 3.000000
PULSER VOLTAGE (V) = 400
NUMBER OF STACKS = 32
SURVEY MODE = Reflection
SOURCE DATA FILE = C:\EKKO\srs_3

PROCESSING SELECTED:

Trace Stacking : 1
Points Stacking : 1
Trace Differencing: N
Gain Type : CONSTANT
Factor : 50.000
Selection : Time = all
Trace = 1 to 52

PLOT LAYOUT PARAMETERS:

Trace Spacing : 0.100"
Trace Width : 0.200"
Trace Position : 1.000" to 6.000"
Left/Right Margin : 0.500" / 0.000"
Border Size : 0.500"
Page Length/Width : 11.000" / 8.500"
Printer Name : HP LaserJet II 300dpi

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PulseEKKO Data Sheet

DATA FILE #1 PARAMETERS:

Data File = c:\ekko\50_srs.hd

Savannah River Site

K Reactor Initial Site Characterization
12/09/96

NUMBER OF TRACES = 53
NUMBER OF PTS/TRC = 312
TIMEZERO AT POINT = 28
TOTAL TIME WINDOW = 250
STARTING POSITION = 0.000000
FINAL POSITION = 52.000000
STEP SIZE USED = 1.000000
POSITION UNITS = metres
NOMINAL FREQUENCY = 200.000000
ANTENNA SEPARATION = 3.000000
PULSER VOLTAGE (V) = 400
NUMBER OF STACKS = 32
SURVEY MODE = Reflection
SOURCE DATA FILE = C:\EKKO\srs_0

PROCESSING SELECTED:

Trace Stacking : 1
Points Stacking : 1
Trace Differencing: N
Gain Type : CONSTANT
Factor : 50.000
Selection : Time = all
Trace = 1 to 52

PLOT LAYOUT PARAMETERS:

Trace Spacing : 0.100"
Trace Width : 0.200"
Trace Position : 1.000" to 6.000"
Left/Right Margin : 0.500" / 0.000"
Border Size : 0.500"
Page Length/Width : 11.000" / 8.500"
Printer Name : HP LaserJet II 300dpi

PulseEKKO Data Sheet

DATA FILE #1 PARAMETERS:

Data File = C:\EKKO\0_srs.hd

Savannah River Site

K Reactor Initial Site Characterization

26/09/96

NUMBER OF TRACES = 53
NUMBER OF PTS/TRC = 250
TIMEZERO AT POINT = 22
TOTAL TIME WINDOW = 200
STARTING POSITION = 0.0000
FINAL POSITION = 52.0000
STEP SIZE USED = 1.0000
POSITION UNITS = metres
NOMINAL FREQUENCY = 200.00
ANTENNA SEPARATION = 1.0000
PULSER VOLTAGE (V) = 400
NUMBER OF STACKS = 16
SURVEY MODE = Reflection

PROCESSING SELECTED:

Trace Stacking : 1
Points Stacking : 1
Trace Differencing: N
Gain Type : CONSTANT
Factor : 50.000
Selection : Time = all
Trace = 1 to 110

PLOT LAYOUT PARAMETERS:

Trace Spacing : 0.050"
Trace Width : 0.150"
Trace Position : 1.000" to 6.000"
Left/Right Margin : 0.500" / 0.000"
Border Size : 0.500"
Page Length/Width : 11.000" / 8.500"
Printer Name : HP LasetJet II 150dpi

PulseEKKO Data Sheet

DATA FILE #1 PARAMETERS:

Data File = C:\EKKO\6_srs.hd

Savannah River Site

K Reactor Initial Site Characterization

26/09/96

NUMBER OF TRACES = 52
NUMBER OF PTS/TRC = 250
TIMEZERO AT POINT = 20
TOTAL TIME WINDOW = 200
STARTING POSITION = 0.0000
FINAL POSITION = 51.0000
STEP SIZE USED = 1.0000
POSITION UNITS = metres
NOMINAL FREQUENCY = 200.00
ANTENNA SEPARATION = 1.0000
PULSER VOLTAGE (V) = 400
NUMBER OF STACKS = 16
SURVEY MODE = Reflection

PROCESSING SELECTED:

Trace Stacking : 1
Points Stacking : 1
Trace Differencing: N
Gain Type : CONSTANT
Factor : 50.000
Selection : Time = all
Trace = 1 to 110

PLOT LAYOUT PARAMETERS:

Trace Spacing : 0.050"
Trace Width : 0.150"
Trace Position : 1.000" to 6.000"
Left/Right Margin : 0.500" / 0.000"
Border Size : 0.500"
Page Length/Width : 11.000" / 8.500"
Printer Name : HP LasetJet II 150dpi

PulseEKKO Data Sheet

DATA FILE #1 PARAMETERS:

Data File = C:\EKKO\12_srs.hd

Savannah River Site

K Reactor Initial Site Characterization

26/09/96

NUMBER OF TRACES = 52
NUMBER OF PTS/TRC = 250
TIMEZERO AT POINT = 14
TOTAL TIME WINDOW = 200
STARTING POSITION = 0.0000
FINAL POSITION = 51.0000
STEP SIZE USED = 1.0000
POSITION UNITS = metres
NOMINAL FREQUENCY = 200.00
ANTENNA SEPARATION = 1.0000
PULSER VOLTAGE (V) = 400
NUMBER OF STACKS = 16
SURVEY MODE = Reflection

PROCESSING SELECTED:

Trace Stacking : 1
Points Stacking : 1
Trace Differencing: N
Gain Type : CONSTANT
Factor : 50.000
Selection : Time = all
Trace = 1 to 110

PLOT LAYOUT PARAMETERS:

Trace Spacing : 0.050"
Trace Width : 0.150"
Trace Position : 1.000" to 6.000"
Left/Right Margin : 0.500" / 0.000"
Border Size : 0.500"
Page Length/Width : 11.000" / 8.500"
Printer Name : HP LasetJet II 150dpi

PulseEKKO Data Sheet

DATA FILE #1 PARAMETERS:

Data File = C:\EKKO\ln4_4ew.hd

Savannah River Site

Line 15

06/10/96

NUMBER OF TRACES = 90

NUMBER OF PTS/TRC = 640

TIMEZERO AT POINT = 57

TOTAL TIME WINDOW = 512

STARTING POSITION = 0.0000

FINAL POSITION = 44.5000

STEP SIZE USED = 0.5000

POSITION UNITS = feet

NOMINAL FREQUENCY = 200.00

ANTENNA SEPARATION = 2.0000

PULSER VOLTAGE (V) = 400

NUMBER OF STACKS = 1

SURVEY MODE = Reflection

PROCESSING SELECTED:

Trace Stacking : 1

Points Stacking : 1

Trace Differencing: N

Gain Type : CONSTANT

Factor : 50.000

Selection : Time = all

Trace = 1 to 110

PLOT LAYOUT PARAMETERS:

Trace Spacing : 0.050"

Trace Width : 0.150"

Trace Position : 1.000" to 6.000"

Left/Right Margin : 0.500" / 0.000"

Border Size : 0.500"

Page Length/Width : 11.000" / 8.500"

Printer Name : HP LasetJet II 150dpi

PulseEKKO Data Sheet

DATA FILE #1 PARAMETERS:

Data File = .C:\EKKO\ln7_6ew.hd

Savannah River Site

Line 15

06/10/96

NUMBER OF TRACES = 90
NUMBER OF PTS/TRC = 640
TIMEZERO AT POINT = 55
TOTAL TIME WINDOW = 512
STARTING POSITION = 0.0000
FINAL POSITION = 44.5000
STEP SIZE USED = 0.5000
POSITION UNITS = feet
NOMINAL FREQUENCY = 200.00
ANTENNA SEPARATION = 2.0000
PULSER VOLTAGE (V) = 400
NUMBER OF STACKS = 1
SURVEY MODE = Reflection

PROCESSING SELECTED:

Trace Stacking : 1

Points Stacking : 1

Trace Differencing: N

Gain Type : CONSTANT

Factor : 50.000

Selection : Time = all

Trace = 1 to 110

PLOT LAYOUT PARAMETERS:

Trace Spacing : 0.050"

Trace Width : 0.150"

Trace Position : 1.000" to 6.000"

Left/Right Margin : 0.500" / 0.000"

Border Size : 0.500"

Page Length/Width : 11.000" / 8.500"

Printer Name : HP LaserJet II 150dpi

PulseEKKO Data Sheet

DATA FILE #1 PARAMETERS:

Data File = C:\EKKO\line12.hd

Savannah River Site

Line 12

06/10/96

NUMBER OF TRACES = 75
NUMBER OF PTS/TRC = 640
TIMEZERO AT POINT = 54
TOTAL TIME WINDOW = 512
STARTING POSITION = 0.0000
FINAL POSITION = 37.0000
STEP SIZE USED = 0.5000
POSITION UNITS = feet
NOMINAL FREQUENCY = 200.00
ANTENNA SEPARATION = 2.0000
PULSER VOLTAGE (V) = 400
NUMBER OF STACKS = 1
SURVEY MODE = Reflection

PROCESSING SELECTED:

Trace Stacking : 1
Points Stacking : 1
Trace Differencing: N
Gain Type : CONSTANT
Factor : 50.000
Selection : Time = all
Trace = 1 to 110

PLOT LAYOUT PARAMETERS:

Trace Spacing : 0.050"
Trace Width : 0.150"
Trace Position : 1.000" to 6.000"
Left/Right Margin : 0.500" / 0.000"
Border Size : 0.500"
Page Length/Width : 11.000" / 8.500"
Printer Name : HP LasetJet II 150dpi

PulseEKKO Data Sheet

DATA FILE #1 PARAMETERS:

Data File = C:\EKKO\line15.hd

Savannah River Site

Line 15

06/10/96

NUMBER OF TRACES = 102
NUMBER OF PTS/TRC = 640
TIMEZERO AT POINT = 58
TOTAL TIME WINDOW = 512
STARTING POSITION = 0.0000
FINAL POSITION = 50.5000
STEP SIZE USED = 0.5000
POSITION UNITS = feet
NOMINAL FREQUENCY = 200.00
ANTENNA SEPARATION = 2.0000
PULSER VOLTAGE (V) = 400
NUMBER OF STACKS = 1
SURVEY MODE = Reflection

PROCESSING SELECTED:

Trace Stacking : 1

Points Stacking : 1

Trace Differencing: N

Gain Type : CONSTANT

Factor : 50.000

Selection : Time = all

Trace = 1 to 110

PLOT LAYOUT PARAMETERS:

Trace Spacing : 0.050"

Trace Width : 0.150"

Trace Position : 1.000" to 6.000"

Left/Right Margin : 0.500" / 0.000"

Border Size : 0.500"

Page Length/Width : 11.000" / 8.500"

Printer Name : HP LaserJet II 150dpi

PulseEKKO Data Sheet

DATA FILE #1 PARAMETERS:

Data File = C:\EKKO\line16.hd

Savannah River Site

Line 16

06/10/96

NUMBER OF TRACES = 60
NUMBER OF PTS/TRC = 640
TIMEZERO AT POINT = 56
TOTAL TIME WINDOW = 512
STARTING POSITION = 0.0000
FINAL POSITION = 29.5000
STEP SIZE USED = 0.5000
POSITION UNITS = feet
NOMINAL FREQUENCY = 200.00
ANTENNA SEPARATION = 2.0000
PULSER VOLTAGE (V) = 400
NUMBER OF STACKS = 1
SURVEY MODE = Reflection

PROCESSING SELECTED:

Trace Stacking : 1
Points Stacking : 1
Trace Differencing: N
Gain Type : CONSTANT
Factor : 50.000
Selection : Time = all
Trace = 1 to 110

PLOT LAYOUT PARAMETERS:

Trace Spacing : 0.050"
Trace Width : 0.150"
Trace Position : 1.000" to 6.000"
Left/Right Margin : 0.500" / 0.000"
Border Size : 0.500"
Page Length/Width : 11.000" / 8.500"
Printer Name : HP LasetJet II 150dpi

PulseEKKO Data Sheet

DATA FILE #1 PARAMETERS:

Data File = C:\EKKO\line32_6.hd

Savannah River Site

Line 32'6"

06/10/96

NUMBER OF TRACES = 45
NUMBER OF PTS/TRC = 640
TIMEZERO AT POINT = 57
TOTAL TIME WINDOW = 512
STARTING POSITION = 0.0000
FINAL POSITION = 22.0000
STEP SIZE USED = 0.5000
POSITION UNITS = feet
NOMINAL FREQUENCY = 200.00
ANTENNA SEPARATION = 2.0000
PULSER VOLTAGE (V) = 400
NUMBER OF STACKS = 1
SURVEY MODE = Reflection

PROCESSING SELECTED:

Trace Stacking : 1
Points Stacking : 1
Trace Differencing: N
Gain Type : CONSTANT
Factor : 50.000
Selection : Time = all
Trace = 1 to 110

PLOT LAYOUT PARAMETERS:

Trace Spacing : 0.050"
Trace Width : 0.150"
Trace Position : 1.000" to 6.000"
Left/Right Margin : 0.500" / 0.000"
Border Size : 0.500"
Page Length/Width : 11.000" / 8.500"
Printer Name : HP LasetJet II 150dpi

PulseEKKO Data Sheet

DATA FILE #1 PARAMETERS:

Data File = C:\EKKO\line33_6.hd

Savannah River Site

Line 33'6"

06/10/96

NUMBER OF TRACES = 44
NUMBER OF PTS/TRC = 640
TIMEZERO AT POINT = 57
TOTAL TIME WINDOW = 512
STARTING POSITION = 0.0000
FINAL POSITION = 21.5000
STEP SIZE USED = 0.5000
POSITION UNITS = feet
NOMINAL FREQUENCY = 200.00
ANTENNA SEPARATION = 2.0000
PULSER VOLTAGE (V) = 400
NUMBER OF STACKS = 1
SURVEY MODE = Reflection

PROCESSING SELECTED:

Trace Stacking : 1
Points Stacking : 1
Trace Differencing: N
Gain Type : CONSTANT
Factor : 50.000
Selection : Time = all
Trace = 1 to 110

PLOT LAYOUT PARAMETERS:

Trace Spacing : 0.050"
Trace Width : 0.150"
Trace Position : 1.000" to 6.000"
Left/Right Margin : 0.500" / 0.000"
Border Size : 0.500"
Page Length/Width : 11.000" / 8.500"
Printer Name : HP LasetJet II 150dpi

PulseEKKO Data Sheet

DATA FILE #1 PARAMETERS:

Data File = C:\EKKO\line34_6.hd

Savannah River Site

Line 15

06/10/96

NUMBER OF TRACES = 101

NUMBER OF PTS/TRC = 640

TIMEZERO AT POINT = 55

TOTAL TIME WINDOW = 512

STARTING POSITION = 0.0000

FINAL POSITION = 50.0000

STEP SIZE USED = 0.5000

POSITION UNITS = feet

NOMINAL FREQUENCY = 200.00

ANTENNA SEPARATION = 2.0000

PULSER VOLTAGE (V) = 400

NUMBER OF STACKS = 1

SURVEY MODE = Reflection

PROCESSING SELECTED:

Trace Stacking : 1

Points Stacking : 1

Trace Differencing: N

Gain Type : CONSTANT

Factor : 50.000

Selection : Time = all

Trace = 1 to 110

PLOT LAYOUT PARAMETERS:

Trace Spacing : 0.050"

Trace Width : 0.150"

Trace Position : 1.000" to 6.000"

Left/Right Margin : 0.500" / 0.000"

Border Size : 0.500"

Page Length/Width : 11.000" / 8.500"

Printer Name : HP LasetJet II 150dpi

PulseEKKO Data Sheet

DATA FILE #1 PARAMETERS:

Data File = C:\EKKO\line35_6.hd

Savannah River Site

Line 35'6"

06/10/96

NUMBER OF TRACES = 40
NUMBER OF PTS/TRC = 640
TIMEZERO AT POINT = 59
TOTAL TIME WINDOW = 512
STARTING POSITION = 0.0000
FINAL POSITION = 19.5000
STEP SIZE USED = 0.5000
POSITION UNITS = feet
NOMINAL FREQUENCY = 200.00
ANTENNA SEPARATION = 2.0000
PULSER VOLTAGE (V) = 400
NUMBER OF STACKS = 1
SURVEY MODE = Reflection

PROCESSING SELECTED:

Trace Stacking : 1

Points Stacking : 1

Trace Differencing: N

Gain Type : CONSTANT

Factor : 50.000

Selection : Time = all

Trace = 1 to 110

PLOT LAYOUT PARAMETERS:

Trace Spacing : 0.050"

Trace Width : 0.150"

Trace Position : 1.000" to 6.000"

Left/Right Margin : 0.500" / 0.000"

Border Size : 0.500"

Page Length/Width : 11.000" / 8.500"

Printer Name : HP LaserJet II 150dpi

PulseEKKO Data Sheet

DATA FILE #1 PARAMETERS:

Data File = C:\EKKO\line36_6.hd

Savannah River Site

Line 36'6"

08/10/96

NUMBER OF TRACES = 40
NUMBER OF PTS/TRC = 640
TIMEZERO AT POINT = 55
TOTAL TIME WINDOW = 512
STARTING POSITION = 0.0000
FINAL POSITION = 19.5000
STEP SIZE USED = 0.5000
POSITION UNITS = feet
NOMINAL FREQUENCY = 200.00
ANTENNA SEPARATION = 2.0000
PULSER VOLTAGE (V) = 400
NUMBER OF STACKS = 1
SURVEY MODE = Reflection

PROCESSING SELECTED:

Trace Stacking : 1

Points Stacking : 1

Trace Differencing: N

Gain Type : CONSTANT

Factor : 50.000

Selection : Time = all

Trace = 1 to 110

PLOT LAYOUT PARAMETERS:

Trace Spacing : 0.050"

Trace Width : 0.150"

Trace Position : 1.000" to 6.000"

Left/Right Margin : 0.500" / 0.000"

Border Size : 0.500"

Page Length/Width : 11.000" / 8.500"

Printer Name : HP LaserJet II 150dpi

0160W

Appendix D

Seismic Crosshole Data Pre- and Post Melt Records

Conducted by GT Geosystems Engineering
South of K-Seepage Basin, Aiken, S.C.
Field Tests, October 1996 and January 1997

1.

CROSSHOLE TEST RESULTS : Shear Wave Velocities

Site: Savannah River Site @Aiken, South Carolina

Performed by: S. Mills & D. Zywicki

Date Performed: Thursday, October 3, 1996

Distances:

S-R1 (feet): $\frac{3.5}{1} = \frac{1.07}{1}$ meters

S-R2 (feet): $\frac{15.5}{1} = \frac{4.72}{1}$ meters

S-R3 (feet): $\frac{6.25}{1} = \frac{1.91}{1}$ meters

Depth (ft)	Depth (m)	Source-Receiver 1			Source-Receiver 2			Pseudo Interval Receiver 1-Receiver2			Source-Receiver 3			Average	
		Shear Wave Travel Time (sec)	Velocity (fps)	Velocity (mps)	Shear Wave Travel Time (sec)	Velocity (fps)	Velocity (mps)	Shear Wave Travel Time (sec)	Velocity (fps)	Velocity (mps)	Shear Wave Travel Time (sec)	Velocity (fps)	Velocity (mps)	Velocity (fps)	Velocity (mps)
1.0	0.3	0.0112200	311.94	95.08	0.0351200	441.34	134.52	0.0239000	502.09	153.04	0.0154400	404.79	123.38	415.04	126.51
2.0	0.6	0.0124700	280.67	85.55	0.0355000	436.62	133.08	0.0230300	521.06	158.82	0.0153400	407.43	124.19	411.45	125.41
3.0	0.9	0.0107200	326.49	99.51	0.0353100	438.97	133.80	0.0245900	488.00	148.74	0.0143400	435.84	132.85	422.33	128.73
4.0	1.2	0.0093750	373.33	113.79	0.0306900	505.05	153.94	0.0213150	562.98	171.60	0.0129100	484.12	147.56	481.37	146.72
5.0	1.5	0.0084060	416.37	126.91	0.0288100	538.01	163.98	0.0204040	588.12	179.26	0.0115600	540.66	164.79	520.79	158.74
6.0	1.8	0.0090310	387.55	118.13	0.0281200	551.21	168.01	0.0190890	628.63	191.61	0.0116200	537.87	163.94	526.32	160.42
7.0	2.1	0.0074690	468.60	142.83	0.0211900	731.48	222.95	0.0137210	874.57	266.57	0.0082190	760.43	231.78	708.77	216.03

POST-VITRIFICATION Crosshole Test Results :
Shear Wave Velocities

Site: Savannah River Site @Aiken, South Carolina

Performed by: Dr. G. Rix, S. Mills, & D. Zywicki

Date Performed: Friday, January 17, 1997

Ground Surface Distances:

Single (feet): $\frac{5.7}{1} = \frac{1.73}{1}$ meters

Double (feet): $\frac{8.45}{1} = \frac{2.58}{1}$ meters

Single Bulb						Double Bulb					
Horizontal Subsurface Distance (ft)	Depth (ft)	Depth (m)	Shear Wave Travel Time (sec)	Velocity (fps)	Velocity (mps)	Horizontal Subsurface Distance (ft)	Depth (ft)	Depth (m)	Shear Wave Travel Time (sec)	Velocity (fps)	Velocity (mps)
5.4687	2.0	0.61	0.006484	843.41	257.07	8.45	1	0.30	0.0075975	1116.11	340.19
5.3721	3.0	0.91	0.007695	698.13	212.79	8.45	2	0.61	0.0096090	879.38	268.04
5.3584	4.0	1.22	0.008086	662.68	201.99	8.45	3	0.91	0.0082030	1030.11	313.98
5.3520	5.0	1.52	0.008008	668.33	203.71	8.45	4	1.22	0.0082810	1020.41	311.02
5.3496	6.0	1.83	0.0090231	592.88	180.71	8.45	5	1.52	0.0089060	948.80	289.19
5.2979	7.0	2.13	0.006914	766.26	233.56	8.45	6	1.83	0.0102750	822.68	250.75
5.2464	8.0	2.44	0.005273	994.96	303.26	8.45	7	2.13	0.0096090	879.44	268.05
5.1951	9.0	2.74	0.003203	1621.93	494.37	8.45	8	2.44	0.0063280	1335.34	407.01
						8.45	9	2.74	0.0046090	1833.89	558.97

Source - Receiver 1 == Depths: 1ft, 2ft, 3ft, 4ft, 5ft, 6ft, 7ft

TIME DOMAIN GRAPHS

Figure 1A: Source @ 1 ft

Figure 1B: Receiver1 @ 1 ft

Figure 2A: Source @ 2 ft

Figure 2B: Receiver1 @ 2 ft

Figure 3A: Source @ 3 ft

Figure 3B: Receiver1 @ 3 ft

Figure 4A: Source @ 4 ft

Figure 4B: Receiver1 @ 4 ft

Figure 5A: Source @ 5 ft

Figure 5B: Receiver1 @ 5 ft

Figure 6A: Source @ 6 ft

Figure 6B: Receiver1 @ 6 ft

Figure 7A: Source @ 7 ft

Figure 7B: Receiver1 @ 7 ft

Source - Receiver 2 == Depths: 1ft, 2ft, 3ft, 4ft, 5ft, 6ft, 7ft
TIME DOMAIN GRAPHS

Figure 1A: Source @ 1 ft

Figure 1B: Receiver2 @ 1 ft

Figure 2A: Source @ 2 ft

Figure 2B: Receiver2 @ 2 ft

Figure 3A: Source @ 3 ft

Figure 3B: Receiver2 @ 3 ft

Figure 4A: Source @ 4 ft

Figure 4B: Receiver2 @ 4 ft

Figure 5A: Source @ 5 ft

Figure 5B: Receiver2 @ 5 ft

Figure 6A: Source @ 6 ft

Figure 6B: Receiver2 @ 6 ft

Figure 7A: Source @ 7 ft

Figure 7B: Receiver2 @ 7 ft

Source - Receiver 3 == Depths: 1ft, 2ft, 3ft, 4ft, 5ft, 6ft, 7ft
TIME DOMAIN GRAPHS

Figure 1A: Source @ 1 ft

Figure 1B: Receiver3 @ 1 ft

Figure 2A: Source @ 2 ft

Figure 2B: Receiver3 @ 2 ft

Figure 3A: Source @ 3 ft

Figure 3B: Receiver3 @ 3 ft

Figure 4A: Source @ 4 ft

Figure 4B: Receiver3 @ 4 ft

Figure 5A: Source @ 5 ft

Figure 5B: Receiver3 @ 5 ft

Figure 6A: Source @ 6 ft

Figure 6B: Receiver3 @ 6 ft

Figure 7A: Source @ 7 ft

Figure 7B: Receiver3 @ 7 ft

APPENDIX E

Melt level monitoring by Time Domain Reflectometry and ultrasonic depth measurement

Author: James Tarpley at SRCCA02

Date: 11/22/96 5:06 PM

Priority: Normal

TO: Robert Blundy at SRCCB10, Martha Thompson at SRCCB05, Peter Zionkowski at SRCCB05, Jeffery05 Williams at MAILHUB, David Herman at MAILHUB, Ray Schumacher at SRCCA01
CC: bob.newsom@etri.gatech.edu at MAILHUB, lou.circeo@arch.gatech.edu at MAILHUB, paul.mayne@ce.gatech.edu at MAILHUB, Kirsten Aylward at SRCCA19, Malcolm Kyle at MAILHUB, Alex Henderson at SRCCA01, Ivan Lewis at MAILHUB, Thomas French at SRCCA01

Subject: ISPV Instrumentation Report

Here is the summary report of the instrumentation provided by Equipment Engineering for the ISPV project. 8x10 photos will be available shortly. I just reviewed the negatives. There has been some delay in the video tape copying. I had to perform surgery to recover one of the 8mm tapes. My involvement in this project was a last minute effort with little planning. Therefore, the results I have to present are not the most scientific but perhaps more predominately observations. I wanted to capture everything that might be significant that would potentially aid future development for field deployment of this technology. Thanks to Martha Thompson, Nate Miller and Carla Loftin for assisting with this effort. For those that can, view the attached MS-Word file. For those that can't, I have pasted the unformatted text below.

Instrumentation for ISPV
James M Tarpley
Equipment Engineering
Savannah River Technology Center
11-22-96

Summary:

This is a summary report of the instrumentation provided by Equipment Engineering for the ISPV (In-Situ Plasma Vitrification) demonstration project conducted by Environmental Restoration. An ultrasonic rangefinder and Time Domain Reflectometer (TDR) were provided to measure the depth below ground of the melt pool generated by the plasma arc torch. This report will serve to document the results of these field measurements and provide some insight into how the measurements worked and their potential for deployment. The intent of the ultrasonic detector was to make depth measurements in the hole when the plasma arc torch was withdrawn for examination. The success of this method was limited. TDR was used to electronically measure the depth of the roof of the melt during vitrification by using an ordinary coaxial cable as a sacrificial probe. This method seemed to work well although the field data has not been correlated.

Purpose:

The purpose of the provided instrumentation is to provide an indication of the depth of the melt pool during operation of the plasma arc torch. The depth of the melt pool must be known for several reasons: 1. Optimize heat transfer from the torch flame to the earth. 2. Avoid quenching the flame by getting the torch tip too close to the melt. 3. Avoid contaminating the torch tip by contacting the melt. 4. Avoid developing air pockets and voids by getting too far from the melt. This condition defeats the purpose of locking all the earth as one solid rock for structural integrity. It also allows the possibility of a sudden and dangerous contaminated gas release. In terms of specific measurement applications, the depth measurements are needed during the vitrification process in order to operate the torch continuously. Also, for the purpose of supporting the demonstration project, there were planned torch operational pauses for withdrawal and examination of the torch. This presented an opportunity to deploy equipment that depends on an unobstructed line of sight to the melt in the hole.

Ultrasonic Detector:

An ultrasonic detector was purchased from Cole Parmer to range-find and measure the depth between runs of the torch. There is a class of non-contact detectors that are typically used for liquid tank level

devices for measurement of the 0 to 8 foot depth of a hole in the earth. A restrictive product search yielded the Cole Parmer model E-43251-50 detector and model E-43251-30 controller. The electrostatic detector was chosen over the piezo unit after consulting with Cole Parmer technical representatives. The measurement range is 0.6 to 30 feet. This AC powered controller was chosen because of it's rugged weather-tight enclosure. A "wave guide" model E-43251-81 (shaped entry pipe extension) was purchased against recommendation of the applications engineers in order to experiment and see if it would help avoid the near field triggering and act as a heat protecting shroud. It did not prove useful for the measurements. A mounting bracket model E-43251-90 was purchased in order to fixture the detector. Although the holes were sleeve lined with a somewhat rusty 8 inch schedule 40 steel pipe, the restrictive path proved that beam reflections and false triggering could be a problem.

Cole Parmer is simply a reseller of the Lundahl Instruments DST-1001 and DCR-1003. Assistance in the programming of the sensitivity, acoustic pulse energy level and the blanking range was obtained from Rod Stott at Lundahl. This unit is highly programmable and the default settings had to be altered to accommodate our unusual application. For deployment, holding the detector steady in just the right position relative to the hole is very important. The detector must be concentric to the hole and collinear with the center, otherwise the 7 to 8 degree beam spread would produce a false reflection part way down the pipe. A swing arm bracket was fabricated to mount the detector to the platform so that it would hold the necessary position for measurements and swing out of the way when not in use. During actual use however, a heat deflector was used for the torch which precluded mounting the detector. The bracket was used but was hand positioned using the platform as a brace.

The ultrasonic measurement method gave viable readings only at the first vitrification break. All of the subsequent readings were short I was suspicious that the detector may have been heat damaged, but it proved operational after the vitrification was complete. There are several possible explanations for the erroneous readings. During our preliminary tests, the unit proved successful without the "dog house" heat deflector. The heat shield remained in position even when the torch was removed. It encroached and reduced visible access to the hole periphery. Ultrasonic tests should have been performed with the heat shield in place prior to vitrification. It is possible that the ultrasonic detector was triggering on the cold air/hot air interface. The detector works by measuring time of flight of an acoustic "ping" and it's return. The speed of sound through a medium is a function of the density and thus, temperature of that medium. I anticipated an error component due to the variation of the beam velocity. It is possible that the temperature extremes in the beam path created enough of an interface that reflections occurred from the plane of intersection of the hot and cold gases.

Ultrasonic Detector Measurement Data:

Run	Depth Measurement
start of test	not recorded
1st stop	10.72 ft - 18 in = 9.22 ft
2nd stop	2.5 ft - 18 in = 1.0 ft
3rd stop	2.5 ft - 18 in = 1.0 ft
4th stop	2.5 ft - 18 in = 1.0 ft
5th stop (final)	2.5 ft - 18 in = 1.0 ft

I feel that the ultrasonic detector has further potential that could be realized by testing with the actual conditions anticipated during use. Further programming of parameters of operation in the controller and use of fixturing could prove reliable operation. However, application of this technology was intended only for the demonstration project. Opportunity for down hole, line-of-sight, range finding will probably not exist in actual in-situ vitritfication field operations except for at the start of each hole, where simpler methods such as a tape measure could be used.

TDR:

THE NEWEST TACHANA MODEL 54121A four channel test set, already on-hand from other TDR applications, were used for this application. For measurement and detection of the melt pool height, the key realization was that the probe would have to be sacrificial, i.e. I am counting on the magma to dissolve and carry away the copper and dielectric in the coaxial cable probe. This method measures the roof of the melt area rather than the floor. The idea is simple, if you vary the length of a cable, I can measure it and tell you where you are. Similar to the ultrasonic measurement method, TDR works by "pinging" an electromagnetic (rather than acoustic) wave down a wave guide and measuring the return wave characteristics to measure impedance versus time. Time, which in this case is in the tens of pico seconds, translates linearly to distance because we know the speed of propagation of the EM wave in a medium is a function of the dielectric constant of that medium. I was able to achieve a measurement resolution with this equipment of 2.5 inches per division or about ¼ inch. During the vitrification, however, I elected to reduce the resolution so that the entire run of 5 or 6 feet would stay on the screen and not require an intermediate recalibration.

The probe was made with Belden #8233 double shielded 50 ohm coaxial cable. The probe end was left open except for electrical tape to protect from moisture intrusion during the project setup phase. The TDR-set end of the probe was mated with an N-type male connector to 130 feet of mil-spec type RG-11, 75 ohm coaxial cable. The disparity between the two characteristic impedances was intentional and aided in identifying the probe in the TDR waveform trace. The only reason for the double shielding on the probe was that it provided additional stiffness making it easy to insert in the probe hole in the ground. Any inexpensive coaxial cable can be used for this application as the propagation characteristics are not important. Yes, the coax will be consumed at the rate the holes are vitrified, but at 29 cents per foot, the materials cost is not appreciable relative to the operating and energy costs associated with the work. I expect that the dielectric and poly-vinyl sheath do not produce significant off-gasing since they are not free to the atmosphere when melted and should completely decompose at these temperatures. A single coaxial cable could have been used more simply, but the interchangeability and replacability of the probe was desirable. The primary selection criteria for these coaxial cables was their immediate availability.

A calibration factor had to be derived to correlate picoseconds on the instrument display to feet and inches on the cable. You can consult reference materials and manufacturer's data to determine the velocity factor of the cable. The velocity factor, expressed in terms of per cent is a measure of the speed of propagation of an EM wave in this particular medium relative to the speed of light in a vacuum. I chose to experimentally determine the calibration factor to prove the relationship. I made a short probe of 10 inches of the same coax material as the real probe and used the same N-type connector. When I mated and unmated the 10 inch probe, I could see a corresponding 2.0 nS difference in the displayed waveform (2 divisions at 1.0 nS/division). This worked out to a nice even number of 200 pS/inch. This calibration method was simple.

TDR Measurement Data:

Run	Total Movement (inches)	Relative Movement(inches)
Depth (inches)		

start of test	0	79
1st cable penetration	20	59
1st stop	30	49
2nd stop	33	46
3rd stop	44	35
4th stop	54	25
5th stop (final)	70	16

There were two anomalies observed during the operations. During one of the cool evenings without any vitrification operations taking place, I saw a several inch change in the displayed length of the cable and probe combination over time. This is most likely due to the temperature affects on the coaxial feedline and probe. Dielectric constant is a function to some extent of temperature. As the temperature along the approximately 150 feet of cable changed the

velocity factor was shifted due to the temperature change. I do not think that the error due to temperature affects on the probe will be appreciable because the probe is short. The phenomenon can be proven by setting up the same instruments and materials in an environmental chamber. The error can be minimized by shortening the cable between the probe and the TDR set.

The second anomaly was seen as a slow increase and decrease of observed signal noise. The displayed TDR waveform naturally varies in time by a small amount due to the influence of naturally occurring EMI (electromagnetic interference). However, the phenomenon I am describing, was a case in which the signal became so dominated by the noise that the signal was no longer discernable in the noise. This occurred only on the last two runs of the torch and seemed to correlate with the higher power operations and plasma gas flow observed at that time on the Plasma Energy Corp (PEC) remote display. I believe that as part of the field demonstration, and to achieve the desired results, the power levels were increased during the final operations. In increasing the torch power, I believe that the air flow rate used for production of the plasma gas was increased as well. It is possible that with the higher voltage, and gas flow that the arc extended beyond the torch tip and thus was unshielded as in prior operations. The approximately 600-700 amp arc is of course a natural EMI source of terrific magnitude. My observations of the noise corresponded to those of the Thermal Fluids Lab in their thermocouple instrumentation. I believe that additional operations and correlation of the operating parameters could prove the cause of EMI. If the arc is the cause of the EMI, then careful control of the torch operating parameters can be used to eliminate or minimize this effect by keeping the arc contained within the torch body. If a special, application specific torch is developed for in-situ vitrification, I recommend that the torch design accommodate containment of longer arc catenations for higher power operating conditions.

The cable end was initially 79 inches below the surface of the ground. The probe cable was intentionally inserted to a greater depth than the melt hole depth. The first observed measurement change occurred when the magma melted through the cable, 20 inches above the end. The final reading of 11 inches can be compared to the actual of 18 inches. After the tests were complete, the extracted probe cable measured 18 inches below the tape marking the ground surface level. This difference is likely due to the extreme temperature change occurring from 8:00 AM to 1:00 PM. The temperature change during this time was probably close to 30 degrees F.

I believe that TDR methods have potential for field operations of in-situ vitrification. This measurement technique offers the capability to be used while operating the torch. Other less expensive instruments than the HP oscilloscope could be more easily deployed. A Tektronix model 1503 TDR cable tester was obtained to support the project. However, it did not have the resolution necessary to use for this application. The Tektronix model 1502 TDR would be sufficient. The Tektronix gear still requires the operator to interpret a waveform to identify a pulse position, however it reads directly in feet and inches. The HP equipment is really lab-grade and the Tektronics is more appropriately field grade. The HP equipment used for the tests costs approximately \$35,000. The Tektronix 1502 is about \$8500.

Other Potential Methods:

A real-time thermodynamic analysis of the energy going into the hole and the energy coming out may be used to determine the energy transfer efficiency and guide the torch operator during operations. It is assumed that energy transfer efficiency is a direct function of the torch to melt distance. All the necessary measured parameters are available from the PEC instruments except for the temperature of the off-gas. Electric arc energy, cooling water flow rate and inlet/outlet temperatures, plasma gas flow rate and inlet/outlet temperatures could be analyzed to determine how much energy is being imparted to the ground. It appears that with the lap-top computer that was used in the PEC control room, the measured parameters are already available in digital form.

It is possible that the constituency and proportionment of the gaseous emissions from the hole will yield a relationship that is a function

of the torch to heat distance and temperature. Gas sampling and analysis can be performed at the rate of about one per minute when measurements are being made of specific gases. If a single gas can be found that can be used as a key, then the real-time analysis can be made practical. If the off-gassing at all is visible an optical transmissivity measurement could be very simply deployed.

Conclusions:

The TDR method worked well. Improvements can be made to minimize the temperature dependency and reduce the variability of the readings. This method can be readily adapted to the field application and operated by craft personnel. The ultrasonic method has unrealized potential. However, perhaps there is little application beyond the demonstration project. The instrumentation for the ISPV was a success in that much was learned about the particular challenge of this application. Several things were learned about the plasma arc torch operation that impact the instrumentation.

APPENDIX F

Torch operating parameters

TORCH POWER, VOLTAGE AND LOSS, PLASMA GAS FLOW (test 11-12-96, third hole)

— TORCH_POWER
 - - - - - TORCH_VOLTAGE
 PLASMA_GAS_FLOW * 10
 P%_LOSS_IN_WATER * 10

APPENDIX G

Photographs

Plasma torch and support frame in operation

Power supply, control room and water cooling system trailers with torch operating in the foreground

Vitrified monolith from run #3