Demonstration of Plasma In-Situ Vitrification at the K-Reactor Seepage Basin (904-65G)

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

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INTRODUCTION

The Environmental Protection Agency has concluded that vitrification is the "Best Developed Available Technology" (BDAT) for the immobilization of high-level radioactive waste. It has been shown that vitrification of Savannah River Soils produced glass waste forms with lower elemental release of the glass formers than the Environmental Assessment (EA) glass, which has been used as the minimum durability standard for high level waste glass (1-2). Vitrifying radiologically contaminated waste, therefore presents the best opportunity for the Savannah River Site (SRS) to obtain a final permanent closure action for the site's radiologically contaminated waste basins from the environmental regulatory authorities. Vitrification of contaminated soil in-situ rather than the alternative process of exhumation followed by remote processing, presents the additional advantage of minimizing the spread of contamination. In-situ vitrification by "top down" joule heating of soil has been under development for a number of years at PNL and Hanford, and is under-going commercial deployment by the commercial company, GEOSAFE, at Hanford, Oak Ridge and other domestic and foreign locations (3). However, previous test work has shown that SRS soils 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 United States and make "top down" joule heating more susceptible to high energy steam release or glass expulsion events. Therefore, a very high temperature "bottoms up" method of heating which would also incorporate a path for gas release, would be more suitable for in-situ vitrification of the waste sites at SRS.

The Savannah River Technology Center at SRS had begun investigating the possibility of utilizing a plasma torch for "bottoms up" in-situ vitrification and had funded pilot plant scale testing at the Georgia Institute of Technology (GIT) and at Clemson University. By the spring of 1996, the GIT trials had indicated that the process was potentially viable for vitrification of SRS soils but that the process needed to be validated on a clean site at a near production scale, before deployment into a radioactive environment could be contemplated.

Environmental Restoration Division organized this demonstration at a clean location adjacent to the 904-65G, K-Reactor Seepage basin with the objectives of:

- 1) developing realistic cost/effectiveness data for evaluation of the process against other competing remediation technologies such as soil grouting,
- 2) developing the engineering data necessary for possible subsequent full scale deployment at an SRS radiologically contaminated waste unit, and
- 3) 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 and the Thermal Fluids Laboratory of SRTC

This Interim Technical Report provides a preliminary description of the demonstration with conclusions and recommendations based on observations made during the period of the demonstration. A detailed engineering report will be compiled in the near future providing all the data pertaining to the demonstration, together with the cost comparisons, product quality determinations and engineering recommendations for future actions.

PROCESS DESCRIPTION

In operation, a non-transferred arc, plasma torch passes a high voltage, high current DC arc between two electrodes located at the end 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 these very high temperatures, the torch used in this demonstration utilized a water cooled barrel to prolong the life of its components. An alternative process utilizes expendable graphite parts to generate the plasma flame.

In the in-situ plasma vitrification process, a layer of clean soil is first placed over the waste layer or basin floor. A hole is then drilled or punched down through the soil and waste layer with a diameter 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 the melt 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 as it goes and producing a column of glass which contains the majority 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 3 to 5 ft in diameter, depending on the torch power level. In order to vitrify a larger area, the process is repeated on a spacing such that the glass column peripheries would overlap.

The offgas from the torch exits up through the annulus between the torch barrel and the bore hole. Atmospheric pressure is maintained at all times in the subsurface cavity and the possibility of a rapid steam expansion event is virtually non-existent. Due to the very high temperatures involved, the offgas from treating radioactive waste would contain a portion of the radio nuclides that volatilize at low temperatures, which then have to be captured by a hood placed over the hole. The captured offgas would probably be cleaned by quenching, scrubbing and filtration to maintain an overall radio nuclide capture efficiency of 99.99% or better. However for this clean demonstration, calculations indicated that emissions would consist of de-minimis levels of particulates and criteria pollutants, and an exemption from permitting was obtained.

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 an ideal 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.

Site Characterization

When this process is deployed in a CERCLA waste unit closure action, regulatory agencies will require QA of vitrification effectiveness. Remote methods of determining the extent of coverage of the vitrified mass into the waste layer must be proven before this technology can be deployed. A variety of non intrusive geophysical methods were deployed before and after the demonstration to profile the subsurface vitrified masses. These methods included Ground Penetrating Radar, cross hole seismic surveying, surface resistivity, electromagnetic and magnetometer surveys.

Column Shape

Since this demonstration represented a scale up in power level by a factor of 5 or 10X, compared to the GIT work, 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 at the 1MW power level. Other factors that controlled this dimension were the torch operating power level, torch withdrawal rate and torch nozzle height above the melt.

Torch-Melt location

The PEC plasma torch nozzle must be maintained at fairly constant distance above the melt and at no time allowed to contact the melt. At GIT, this was accomplished visually, but in future operations at a contaminated waste unit, this must be accomplished accurately and consistently from a remote location. Therefore it is essential to develop instrumental techniques to accurately monitor the melt level and control the torch position before deployment into a radioactive location can be contemplated. During this demonstration, a combination of ultrasonic distance measurement, Time Domain Reflectometry and soil temperature measurements using thermocouples were evaluated. These instrumental measurements were verified during the demonstration by manual probing with a steel rod.

Glass quality and resistance to leaching.

Glass quality will be determined by sampling and testing of the monolith by the Toxic Characteristic Leaching Procedure (TCLP) (4) and Product Consistency Testing (PCT) (5). Other common glass characterization tools will be employed e.g. x-ray diffraction and scanning electron microscopy.

Off-Gas Analysis

Determination of the partition coefficients for naturally occurring trace heavy metals in the soil between the glass and the offgas will be required. This data would be essential for the design and permitting of the offgas system for a contaminated application.

SEQUENCE OF EVENTS

Before any work was done at the demonstration site, GIT performed the previously listed geophysical surveys at the site to establish baseline soil characteristics. In addition, Shelby tube samples were taken in the vicinity of the vitrification testing to determine soil chemical and physical characteristics.

The available torch barrel was only 4 feet long, which limited the insertion depth of the torch nozzle to a maximum of 3 foot 6 inches. Three holes were bored on 10 foot centers to a depth of approximately 7 feet to allow for initial glass column development at the bottom of the hole. The holes were lined with a thin gage steel tubing to prevent side wall collapse and were flanged at ground level. The first run had the steel liner extending to the bottom of the hole, while all subsequent runs lined the hole to just 11 inches below grade. 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 foot square Exclusion Zone around the torch unless the system electrical lock-out was in place.

A total of three runs were made and a column of soil was successfully vitrified each time. Run #1 utilized a power level of around 650kW for a total run time of 40 minutes. This run produced a fairly narrow glass column and was used to assess how the system operated and to determine the principal operating parameters that affected the vitrified product size and quality. Operating time during run #2 was 105 minutes at an average power level of around 650kW and produced a wider glass column estimated to be between 3 and 4 ft in diameter. Run #3 was a repeat of run #2 but was an attempt to coalesce the columns from runs #2 and #3 by placing the initial borehole of run #3 at a distance of 3 feet from the borehole of run #2. Total run time was 95 minutes with a power level of 950kW being deployed towards the end of the run. Visual observation indicated that coalescence of the vitrified columns had been achieved.

Thermocouple and ultrasonic monitoring was deployed during run #2 and #3 and Time Domain Reflectometry was deployed during run #3.

OBSERVATIONS AND PRELIMINARY CONCLUSIONS

At the time of the writing of this Interim Report, not all of the information is compiled, but the demonstration was considered to have achieved the following successes:

- 1) Use of plasma torch technology for in-situ vitrification of SRS soils was demonstrated to be a practical process on a production scale.

2) The process was inherently safe as no rapid steam or gas expulsions occurred during the demonstration. In fact, a period of time during most runs, the torch was leaking water from the failed front o-ring into the cavity and onto the molten glass with no obvious effect. Small samples of glass showed complete vitrification with little porosity.

3) Essential engineering data necessary for cost comparison and process development was obtained and will be presented later in a final WSRC report.

It is generally agreed that the following lessons learned from the demonstration should be addressed during any further development of the process.

1) The one megawatt, PEC torch employed in the demonstration had a power turn-down of 2:1. In other words, the torch was operational between 600 kW and 1000 kW. The minimum operating power level of 600kW appeared to be excessive at the start of a burn but after the cavity was fully formed, operation at the 900kW power level appeared to be viable.

2) The design of this particular PEC torch is at least 15 years old and clearly suffered from inadequate heat dissipation from around the front o-ring area which caused continual and rapid o-ring failures. This has been improved in more recent PEC torch designs which have been deployed in steel plant applications. The o-rings used by Hydro-Quebec were thought to be a mixture of Buna-N rubber and Viton which have maximum service ratings of 200 °F and 400 °F respectively and appeared to fail by softening which would indicate that the service temperature was only marginally exceeded. Kalrez o-rings have a service limit of 600 °F.

3) About 1/4 to 1/3 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 which distributes the arc over the electrode surfaces. This is a very short life for commercial operation in a radioactive environment.

4) A number of other torch components were made of plastic and were vulnerable to heat generated by the process. These components along with some other torch materials would have to be upgraded before the system could be considered to be industrially viable. At the end of the demonstration, the torch outer casing was found to have become slightly distorted due to overheating and internal stress relief of the stainless steel material.

5) Energy loss into the cooling water consistently ran between 35% and 40%. This is very high and amounts to a low utilization of an expensive energy resource. Either the PEC torch may not be the best type of torch for this application or a specially designed "ruggedized" version would be needed for industrial operation.

6) The Time Domain Reflectometry worked well in detecting the level of the roof cavity. The ultrasonic method of detecting melt level survived above the hot environment 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.

7) From observation, the principal operating parameter that affects the glass column diameter and the torch withdrawal rate is the height of the torch nozzle above the melt. During run #1, the nozzle was maintained at about 2 feet -6 inches above the melt and produced a fairly narrow column. During runs #2 and #3, the torch nozzle was maintained at 2 foot or 1 foot-6 inches respectively above the melt and produced successively wider columns. This emphasizes that the development of a control system for reliably maintaining this dimension is essential.

8) Only minimal visual emission levels were observed at the start of each run which rapidly disappeared after a few minutes of operation. Offgas measurement by EPA Method 29 requires continuous steady state torch operation for at least an hour. A continual run time of this duration was never achieved due to the continual torch o-ring failures. A second attempt will be made to measure offgas emissions on the GIT pilot plant.

REMAINING WORK

At the time of this writing, the geophysical monitoring of the site is to be completed before the vitrified monoliths can be exhumed. The offgas emissions and glass quality determinations also remain to be made before the demonstration can be formally completed.

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