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PLASMA TECHNOLOGY:  
A TOOL FOR HAZARDOUS WASTE VITRIFICATION

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ABSTRACT

A thermal plasma is an electrically conductive gas capable of generating temperatures up to 10000°C near its column. The energy generated by plasma arcs has been recently applied to hazardous waste control. The technology involves subjecting hazardous material to high temperatures with the purpose of immobilizing non-volatile chemical species into a non-leachable matrix. Plasma arc vitrification processing is well suited for special waste disposal requirements. In addition to its ability to sustain high temperatures, other attractive plasma technology features include its flexibility to operate in either an oxidizing or reducing environment, resultant waste volume reduction, low gas throughput, and flexibility to treat a large variety of waste types. Since 1989 the U.S. Army Corps of Engineers Construction Engineering Research Laboratories have been active participants in the research and developmental efforts undertaken to establish this technology as an efficient, economical, and safe hazardous waste immobilization tool. This paper will provide both a plasma arc technology overview and discuss Army/Department of Defense unique hazardous waste disposal needs, such as pyrotechnic smoke assemblies, thermal batteries, proximity fuzes, and contaminated soil which may be met through utilization of this tool. Specific examples of feasibility studies, Construction Productivity Advancement Research (CPAR) projects, and demonstrations undertaken to immobilize environmentally hazardous materials will be provided. Results of completed activities and on-going developments such as mobile plasma arc systems and dual torch demonstration plans will also be presented.

1. INTRODUCTION

Accumulating stockpiles, high storage costs, and the potential for long-term liability are illustrative examples defining the magnitude of the hazardous waste disposal issue facing both governmental and private organizations. The downsizing of the Department of Defense (DoD) presents governmental entities with the challenges of weapons disposal in addition to the necessity to be accountable for annual hazardous waste production. In a recent article highlighting the DoD's 1996 environmental goals, it was stated that the DoD operates 400 industries and disposes of 281 million pounds of hazardous waste annually<sup>1</sup>. The DoD is subject to challenging and strict environmental program standards. One environmental requirement in the recently updated 'Environmental Measures of Merit' is the need for the DoD to reduce its hazardous waste disposal by half (based on a 1992 baseline) by calendar year 1999<sup>2</sup>.

One of the technical challenges in disposing of hazardous wastes is the wide variability in waste media. Hazardous waste may either be solid or liquid waste streams or may contain such environmental hazards as asbestos, heavy metals, or organics or any combination of the mentioned waste components. The U.S. Environmental Protection Agency (EPA) has identified eight Toxicity Characteristic Leaching Procedure (TCLP)

metals which represent environmental hazards and whose disposal are strictly regulated. Figure 1 summarizes these metals and their prevalence in various military applications. In addition, in fiscal year 1994, the U.S. Army generated 640 tons of multi-phase toxic containerized liquids, 523 tons of bulk toxic pumpable liquids, 530 tons of multi-phase containerized solvents, and 128 tons of pumpable solvents<sup>3</sup>. Current treatment of these liquid containing waste streams cost approximately \$1250 to \$2700 per ton.

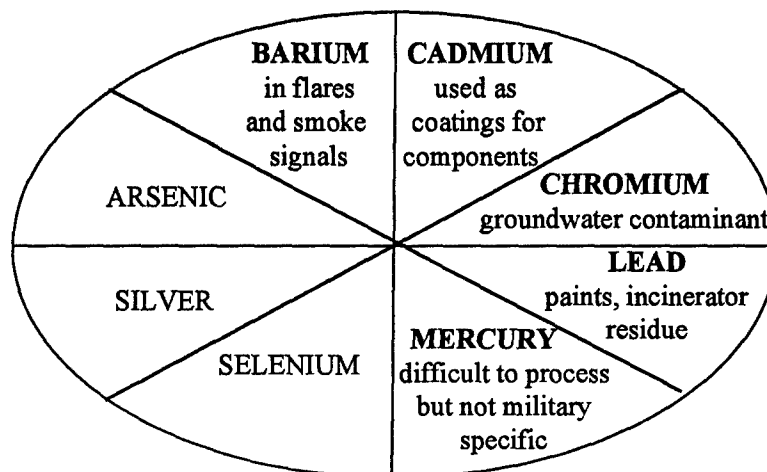


Figure 1. TCLP metals of interest to the military.

Various waste treatment/disposal methodologies have and continue to be evaluated for the environmental remediation of hazardous contaminated materials. Plasma arc technology has been identified as one safe and effective tool for the conversion of contaminated media into chemically inert solids no longer requiring disposal in EPA hazardous waste approved landfills. This paper will summarize the role that plasma arc technology plays in the disposal of DoD hazardous media.

## 2. THERMAL PLASMA ARC TECHNOLOGY

A plasma is an electrically conductive gas. Plasmas are generated when an electromagnetic force causes electrons to be pulled apart from atomic nuclei resulting in an ionized gas. In plasma arc technology, a torch is used to generate controllable plasma temperatures in the range from 1500°C to 7000°C. Several processing benefits associated with plasma technology include high thermal efficiency (resulting in fast reaction kinetics); flexibility in choice of process gas environment; substantial waste volume reduction; high energy density, thus adequacy in utilizing smaller processing reactors; no material pretreatment is required; and the need for less pollution abatement equipment due to the lower demand for air and absence of fossil fuels.

The strategy employed in plasma arc technology involves subjecting contaminated material to the high temperatures of the plasma and chemically combining the non-volatile components into a matrix material, such as soil, so that the processed material, upon solidification, represents an inert, chemically stable material. The resulting matrices will immobilize the hazardous components and prevent them from further contamination of the environment. A schematic overview of several of the various stages involved in thermally treating wastes using plasma technology is provided in figure 2.

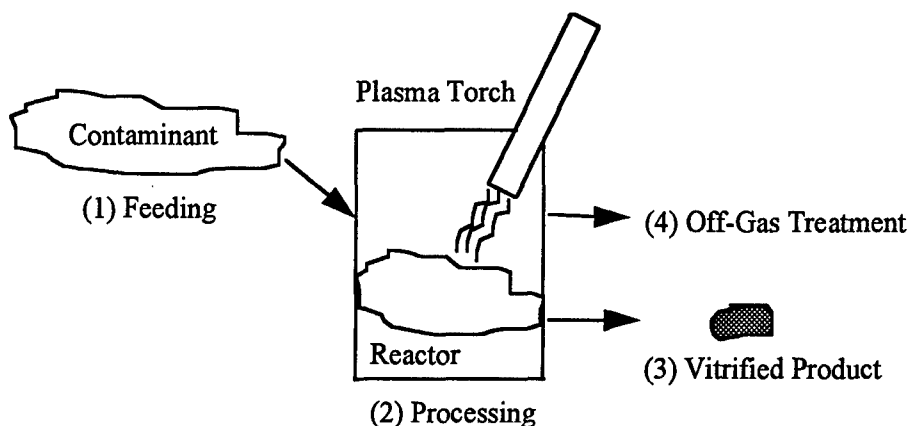


Figure 2. Schematic representation of plasma arc processing.

Introduction of the waste material into the furnace represents the initial challenge in plasma thermal treatment. Currently improvements are being made in regard to development of feeding mechanisms to minimize waste handling. Presently difficulties in designing "universal" feeding mechanisms exist due to the variability of the waste form. For instance, the wastes may be in the form of solid, liquids, large capacity drums, relatively fine particulate, etc., or any combination of the mentioned waste streams.

During the actual processing of the waste, a plasma torch is used to generate the high temperatures (typically several thousand degrees Centigrade) necessary to break the chemical bonds present in the waste material. The original components are then either melted down into elemental form (in the presence of a reducing atmosphere), oxidized into a variety of metal oxides, or a combination of the two, with the metals separating to the bottom of the melt container. The characteristics of the resulting vitrified product are a function of the torch gas/chamber environment, composition of the materials present within the plasma chamber, residence time of the waste during processing, and homogeneity of the treatment. Examples of suppliers of plasma torch systems in the United States include Plasma Energy Corporation (Raleigh, North Carolina), Retech, Incorporated (Ukiah, California), and Westinghouse (Pittsburgh, Pennsylvania).

The plasma treated melt is tapped or poured out of the processing chamber. Once cooled, the solidified mass, referred to as the slag, can be characterized as a vitrified, or glass-like rock. The potential of using this vitrified residue as various by-products such as aggregate, bricks, or gravel is possible. More importantly, once thermal plasma processed, the original hazardous waste now exists as a non-hazardous landfill waste. Various feasibility studies<sup>4,6</sup> have indicated the consistency of slag products to pass toxicity characteristic leaching procedure and durability testing.

Highly volatile chemical species can escape out of the main reaction chamber before they are combined into the melt. Consequently, off-gas treatment systems are necessary to trap particulate and destroy any residual organics before they are released into the atmosphere. Plasma system design engineers are challenged with the need to develop off-gas treatment units which can meet the emissions controls requirements of thermal plasma processing yet keep the costs reasonable so that the vitrification process remains an economic feasibility. An overview of some of the most recent gaseous monitoring and emissions control methodologies used in plasma systems are included in the proceedings of a recent international symposium dedicated to environmental plasma processing applications<sup>7</sup>.

### 3. DOD RELATED PLASMA ACTIVITIES

The DoD generates wastes distinct from commercial industries because of its unique mission. The Army, for instance, generates such items as thermal batteries and proximity fuzes which have no equivalent in the civilian industry. Thermal plasma arc technology is capable of safely and efficiently destroying components or assemblies which contain such toxins as heavy metals and asbestos such that they can be disposed of safely in non-hazardous landfills and so that no "footprint" of the technology that went into the components can be identified.

Plasma arc technology has been a useful thermal treatment tool in the metallurgy and ceramics industry for a number of years. However, only since the middle to late 1980's has the technology been examined as a tool for hazardous waste destruction and immobilization. As indicated in figure 3, the research and developmental (R&D) efforts aimed at applying plasma arc technology toward waste remediation applications involves participants from various institutions. The following section describes some of the collaborative R&D efforts between various organizations, with particular attention being given to the U.S. Army and its sundry plasma technology environmental endeavors.

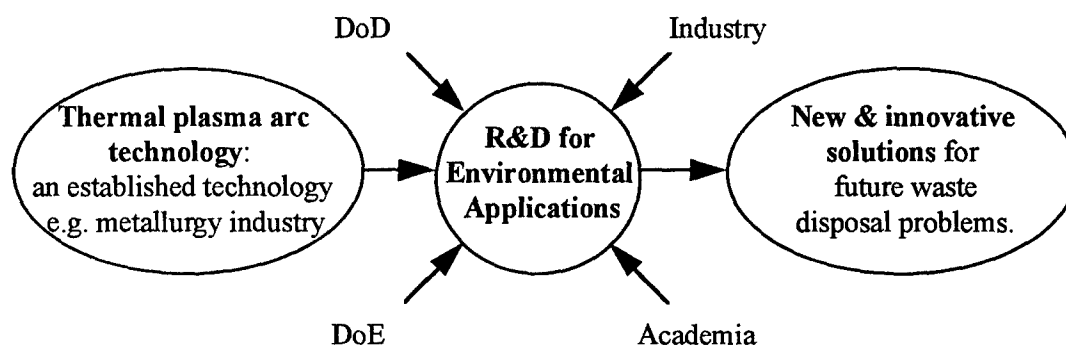


Figure 3. Plasma technology waste remediation players.

#### 3.1 U.S. ARMY ACTIVITIES

##### 3.1.1 Construction Productivity Advancement Research Project

Asbestos fibers and asbestos contaminated materials are tightly regulated as they are carcinogenic. Currently, asbestos removed from both public and private buildings must be deposited in Class I EPA regulated landfills. As landfill charges are volumetrically based, disposal of asbestos can be costly. With the possibility of reduced or prohibited use of Class I landfills, alternative means of dealing with asbestos contaminated materials are urgently needed.

Since 1989, the U.S. Army Corps of Engineers have supported a Construction Productivity Advancement Research Project (CPAR) utilizing plasma arc technology for the conversion of asbestos into harmless rock-like products. The CPAR project was conducted under the coordination of USACERL and the Georgia Institute of Technology using one of Plasma Energy Corporation's torch systems<sup>6,8</sup>. The experimental results of the first stage of this two-phase program indicated that plasma arc technology provided successful immobilization of

chrysotile asbestos while meeting the standards for asbestos exposure. An economic analysis of the plasma processing of asbestos yielded positive indications for the success of a mobile plasma asbestos pyrolysis system (PAPS). It was concluded that a PAPS would be an economically competitive alternative to landfilling asbestos contaminated material. The attractiveness of the technology is apparent when the ever increasing costs for hazardous waste liability and transportation to appropriate landfill sites are considered.

The second phase of the asbestos CPAR project involved supporting the design of a PAPS asbestos treatment unit<sup>9</sup>. Research was conducted on asbestos contaminated items such as floor tile, roofing tile, and transite panels obtained from buildings in the Atlanta area. An economic analysis of a mobile trailer mounted 500 kW torch plasma system indicated that the cost of thermally treating the asbestos using plasma technology would be approximately \$200 per ton. These costs currently approximate the average asbestos treatment costs at Class I EPA approved landfills.

Further R&D work on on-site waste remediation is greatly needed to enhance the technology's capabilities. The significance of asbestos vitrification for the DoD is the reduction in abatement costs relating to asbestos transportation and disposal and the mitigation of a toxic material through conversion into an inert slag.

### 3.1.2 Applied Research and Development Activities through ME, Inc.

The Army has used the DoE contractor, MSE, Inc. (Butte, Montana) to perform various plasma processing runs of Army unique hazardous wastes and to conduct various R&D activities aimed at advancing plasma technology applied to environmental remediation issues. Both the Army Research Development and Engineering Center (ARDEC) and USACERL have and continue to employ the various plasma units at MSE for both applied research and technology advancing developments.

For example, MSE plasma processed proximity fuzes for ARDEC early in calendar year 1993. Processing results indicated that plasma technology was capable of safely and efficiently destroying the fuzes<sup>10</sup>. Presently MSE is conducting the necessary tests suitable for the thermal destruction and demilitarization of stockpiled ordnance<sup>11</sup>. All of the feasibility examinations conducted for Army unique hazardous wastes have documentable challenges and lessons learned ranging from the initial waste feeding through processing to post-analytical product characterization. Some of these challenges include analytical ambiguities due to the presence of previously processed materials within the chamber, emissions concerns, particularly with regard to the generation of NO<sub>x</sub> and particulate formation and the loss of highly volatile organics and heavy metals. Work is continuing in these areas not only by MSE, but by other environmental plasma technology players.

MSE is participating in a technology advancement applied research activity, namely the development of a hybrid torch which can be independently or simultaneously operated in either a transferred or non-transferred arc mode. Both transferred arc torches and non-transferred arc torches have waste streams in which they are best suited for treating (see for example reference 12). By combining the two arc modes, plasma torch operation would be independent of the type of waste. The same torch could be used to treat either solid, liquid, or any combination sludge type waste. The final torch configuration has been selected from a number of proposals with the fabrication and testing of the dual torch in progress. This work is being conducted with the assistance of USACERL. One of the anticipated benefits of the hybrid torch is the reduced cost of processing multi-phase hazardous wastes.

Improvements in the logistics of operating a plasma furnace is a topic that has been studied by MSE with the support of the Army Corps of Engineers. Long term endurance tests have been conducted to pinpoint areas in which improvements in plasma systems could be made to increase the availability of the plasma processing units for environmental remediation efforts. In addition, process optimization studies have yielded observations and

recommendations on the following areas: feeding mechanisms improvements; slag quality control; mass balance accountability; and recommended improvements in gaseous emissions control. Design and implementation of a small scale plasma furnace have proven to be an effective tool for conducting preliminary or initial plasma runs under a more controlled environment with reduced operating costs.

### 3.1.3 Feasibility Studies at Retech, Inc.

Retech, Inc. (Ukiah, California) has participated in various plasma activities for the Army since 1992. Feasibility studies have been conducted on various military unique wastes. In addition to plasma treating soil contaminated with RCRA defined heavy metals and organic compounds, feasibility examinations of thermal batteries, incinerator ash, pyrotechnic smoke assemblies<sup>5</sup>, and sludge<sup>13</sup>, have been conducted using Retech's Plasma Centrifugal Furnace (PCF 1.5) and Small Scale PACT unit. In general, those items containing heavy metals were found to pass TCLP tests while organic destruction was successfully achieved through thermal plasma processing.

Presently, the National Defense Center for Environmental Excellence (NDCEE) is evaluating the use of plasma arc technology for treatment of complex military wastes as initially requested by the U.S. Army. The initial phase of this evaluation involved plasma treating agricultural blast media, glass blast media, medical ash, and plastic blast media<sup>14</sup>. As summarized in an update of the NDCEE<sup>14</sup>, post-phase I testing included consideration of phase II testing waste streams by the representatives of the Tri-Services, NDCEE, and industry. Selection criteria for phase II testing included consideration of current waste treatment cost, DoD waste stream priority level, treatment difficulty level, waste availability for testing; and waste generation rate. One end product of this evaluation will be a report documenting recommendations to the DoD for designing, building, permitting, and installing full-scale plasma waste treatment facilities.

## 3.2 U.S. NAVY ACTIVITIES

Two of the major plasma related activities being coordinated by the U.S. Navy include an Advanced Technology Demonstration (ATD) and an Environmental Security Technology Certification Program (ESTCP). The goal of the ATD is to build a land-based prototype plasma treatment unit subject to specific technical requirements unique to Navy wastes.

In July 1995, ESTCP funding was provided to the U.S. Naval Research Laboratory and the Norfolk Naval Base (Norfolk, Virginia) to establish a plasma treatment unit to destroy dockside waste. Sartwell<sup>15</sup> summarized the various logistical, regulatory, and technical challenges facing the designers and engineers of plasma units capable of destroying mixed solid and liquid hazardous waste. Retech, Inc.'s plasma arc centrifugal treatment (PACT) unit systems have been chosen to support the technical requirements of the program.

## 3.3 U.S. AIR FORCE ACTIVITIES

The U.S. Air Force is developing the potential of plasma arc technology for the stabilization and destruction of bare base waste applications<sup>16</sup>. The Georgia Institute of Technology has recently been funded by the Air Force to develop a full scale technology demonstration for treatment of bare base waste such as domestic and hazardous and medical wastes. Work for this project is being conducted under the coordination of Tyndall Air Force Base.

## 4. SUMMARY

Plasma arc technology is a thermal treatment tool capable of safely and efficiently processing materials containing a large variety of environmental hazards such as heavy metals and asbestos. Utilization of this

technology allows waste candidates to be disposed of safely in non-hazardous landfills; and cost effectively when other waste treatment alternatives fail. Plasma arc technology is undergoing continuous development to improve system reliability and versatility. Research continues in the areas of torch life performance, specifically in the development of longer-life electrodes, while continued development in effluent stream minimization is ongoing to increase technology public and regulatory acceptance. The extensive use of this technology by DoD organizations within the Army and Navy illustrate the potential and feasibility of the technology to meet the ever growing waste disposal needs of an environmentally conscious world community.

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