PLASMA PROCESSING OF COMPACTED DRUMS OF SIMULATED RADIOACTIVE WASTE*

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ABSTRACT

The charter of the Department of Energy (DOE) Office of Technology Development (OTD) is to identify and develop technologies that have potential application in the treatment of DOE wastes. One particular waste of concern within the DOE is transuranic (TRU) waste, which is generated and stored at several DOE sites. High temperature DC arc generated plasma technology is an emerging treatment method for TRU waste, and its use has the potential to provide many benefits in the management of TRU. This paper begins by discussing the need for development of a treatment process for TRU waste, and the potential benefits that a plasma waste treatment system can provide in treating TRU waste. This is followed by a discussion of the results of a project conducted for the DOE to demonstrate the effectiveness of a plasma process for treating supercompacted TRU waste.

INTRODUCTION

The charter of the Department of Energy (DOE) Office of Technology Development (OTD) is to identify and develop technologies that have potential application in the treatment of DOE wastes. One particular type of waste that OTD is concerned with is the general class of waste that is known as transuranic (TRU) waste. TRU waste is defined as waste that contains radioactive elements that have an atomic number greater than that of uranium in quantities exceeding 100 nCi/g. The primary radioactive element of concern for TRU waste is plutonium. One particular source of TRU waste within the DOE will be in a so called supercompacted form, where steel drums containing TRU are compressed in a hydraulic press capable of providing 1996 metric tons (2200 tons) of force.

In order to dispose of its TRU wastes, it may become necessary for DOE to perform some predisposal processing or treatment. There are no processing/treatment technologies currently available that do not have some disadvantages associated with them. DOE has identified plasma arc technology as a potential treatment methodology having a number of advantages. The Waste Technology Development Division of Science Applications International Corporation (SAIC), formerly Haz Answers, Inc., has undertaken the identification and development of the benefits that can be derived from the application of high temperature DC arc-generated plasma technology for the treatment of supercompacted waste forms.

This paper will begin by discussing the need for development of a plasma process for treating TRU waste. This will be followed by a discussion of: the potential benefits that a plasma waste treatment system can provide in treating TRU waste, the plan being developed for a demonstration of a plasma system for treating a simulated supercompacted waste form, and the process scheme that will be employed in the test. Finally, there is a discussion of the expected findings from the test.

BACKGROUND

The DOE operates a number of facilities in the United States that have been involved in Defense Program activities over the past few decades. As a result of the operations at these sites, a significant volume of TRU waste has been and continues to be generated. Any TRU waste that has been generated at a particular DOE site is placed into temporary storage on that site awaiting permanent disposal. Ultimately, DOE plans to dispose of its TRU waste at the Waste Isolation Pilot Plant, a mined geologic repository located in New Mexico. At this time, DOE intends to dispose of its TRU waste in an untreated form.

One of the Defense Program sites operated by the DOE is the Rocky Flats Plant (RFP) in Colorado. RFP generates TRU waste streams that are now being stored onsite, and will ultimately be sent to WIPP for disposal. In general, the components of the TRU waste include paper, plastic (chlorinated and non-chlorinated), cloth, wood and bulk metal. Much of the RFP TRU waste also contains hazardous organic solvents and heavy metal constituents that cause the waste to fall under the regulation of the Resource Conservation and Recovery Act (RCRA), and which require management as hazardous waste as well radioactive waste. Such waste that is both hazardous and radioactive is referred to as mixed waste.

The current RFP RCRA permit granted by the State of Colorado places a limit of 1224 m^3 (1601 yd^3) on the volume of mixed TRU waste RFP can store onsite. The current storage volume of mixed TRU waste is nearing that limit,

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and would likely force a shutdown of the facility if action is not taken. In order to allow RFP to continue to operate within the bounds of its current permit, the DOE has decided to implement a supercompaction process at the site. The supercompactor will receive 132 l (35 gal) drums of hand-packed TRU waste and compress them under 1996 metric tons (2200 tons) of force into a much smaller volume, thus allowing more efficient use of the existing storage volume.

As with other types of TRU waste, the DOE is planning to dispose of this supercompacted waste form in the WIPP facility without treatment. There may be, however, several issues that may have a detrimental impact on the ability of DOE to emplace this untreated mixed TRU waste in WIPP.

Two particular issues arise from the performance criteria for radioactive waste disposal specified in 40 CFR 191 "EPA Radiation Protection Standards for Managing and Disposing of Spent Nuclear Fuel, High-Level Waste and Transuranic Radioactive Wastes". Gases that could be generated by radiolysis and biodegradation of organics in the waste and by the corrosion of metals may have a negative impact on the long-term performance of WIPP. Also, the potential for waste migration due to human intrusion and resulting exposure to radioactive materials must be addressed. Such migration may occur as a result of radioactive constituents leaching from the waste into brine in the repository, and that brine being released to the accessible environment as a result of some form of future drilling operations.

Another issue is founded in the requirements for disposal of hazardous waste under RCRA. RCRA Land Disposal Restrictions (LDRs) require treatment of hazardous waste prior to disposal. RFP estimates that as much as 90% of its TRU waste may not meet the LDRs without treatment. DOE has filed a "no-migration petition" with EPA to exempt waste destined for WIPP from treatment. A temporary petition has been granted for the first phase of the WIPP test period; however, a long-term petition may not be granted, given the present concerns about compliance with 40 CFR 191 performance criteria and potential citizen directed opposition.

In addition to these concerns, requirements for characterization of the TRU waste prior to its emplacement in WIPP may prove difficult and expensive. At this time, DOE is relying upon process knowledge to provide the characterization information needed to assure WIPP will function as designed. However, much of the TRU waste now in storage has been generated as long as twenty years ago, and some amount of concern has been expressed by State of New Mexico regulators about this method of characterization. The State has requested a very rigorous characterization of the waste that will be used for a five year test of the WIPP facility, which will ultimately require that the individual drums of waste be opened, and the contents thoroughly identified and quantified before they can be emplaced in WIPP. It is possible that the State may require a similar rigorous characterization of all waste that will be emplaced at WIPP. Given the difficulty of sampling and analyzing TRU waste, particularly waste that will be in a supercompacted form, and the safety factors that are involved, it may be more cost effective and safer to simply treat the waste, rather than characterize the waste to the degree that may be required for disposal at WIPP.

In addition, the propensity of environmentally focused citizen organizations to bring matters to the jurisdiction of the courts may provide another situation that may force the DOE to treat the waste prior to disposal. Even if the EPA and State of New Mexico grant the permanent "no-migration petition" or agree to a form of characterization acceptable to DOE, citizen based litigation may force a change in these plans, or at the very least, tie up the opening of the facility for perhaps years.

Lastly, placing untreated waste into permanent disposal represents a potential liability. In some cases, what was accepted practice even twenty years ago is no longer even thinkable today. The DOE is now in the process of making plans to exhume and/or remediate past sites where untreated waste was disposed by the accepted methods of the time. Given this potential liability, it may be in DOE's best interest to provide for the treatment of the waste into a more stable state before it is permanently and unretrievably emplaced.

Because of all of these factors, there is cause for concern on the part of DOE that treatment of supercompacted mixed TRU waste may be required prior to final disposal. Should DOE be required to process the RFP supercompacted TRU, the waste may be too dense and encapsulated within the drum for conventional incineration or other conventional treatment technologies to provide adequate treatment. However, it is postulated that high temperature plasma technology can provide the necessary treatment for a compacted waste form.

CHARACTERISTICS OF PLASMA SYSTEM WASTE TREATMENT

Plasma processing is a unique, innovative, and very promising new waste treatment technology that may provide many benefits when used for waste treatment. It is believed that high temperature plasma technology will be particularly effective in the *treatment of mixed* TRU waste. Some of the potential benefits provided by plasma treatment include:

- high efficiency destruction of organics,
- a high-integrity, vitrified final waste form,
- encapsulation of heavy metals and radionuclides in the final waste matrix,
- separation of metal from slag, with TRU components partitioning to the slag phase.
- improved criticality control,
- maximum volume reduction,
- smaller offgas rates minimize particulate entrainment and carryover,
- higher energy density and smaller gas rates allow smaller process equipment,
- a one-step treatment process (no pre- or posttreatment required), and
- capability to process many waste types.

Unlike combustion processes, only a small quantity of gas is involved with generating and maintaining the plasma arc. This characteristic means that plasma heaters can achieve higher temperatures than conventional fossil fuel burners. In this high temperature zone of the primary process chamber, essentially all organics in the waste will pyrolyze and/or combust, leaving no unburned carbon in the residual solid product. A secondary combustion chamber is necessary to provide the destruction required for pyrolyzed/volatilized organics, as well as to achieve the required 99.99% destruction and removal efficiency (DRE) for hazardous organics in the waste.

The remaining inert materials form a molten vitreous slag, which when removed from the furnace, will solidify into a stable final waste form. Past testing and operating experience indicates that bulk metals (such as steel) in the waste being treated separate from the remainder of the waste residue, or "slag". Results of several past studies conducted for the DOE examining the use of melting processes for decontamination of TRU contaminated bulk metals indicate that TRU contaminants will partition into the slag phase to a very high degree. Thus, bulk metals in the waste can be drawn from the plasma process, separated, and reclassified as low-level waste. Hazardous heavy metals in the waste should also remain with the slag, and be sufficiently bound such that the vitrified final product will consistently pass EPA Toxicity Characteristic Leaching Procedure (TCLP) tests for heavy metal leachability. Exclusion of water from the final waste form, together with the potential to include neutron absorbers in final glass matrix, lead to improved criticality control measures for the final waste form.

As mentioned previously, plasma systems use much smaller volumes of gas than do fossil fuel based combustion processes to generate the temperatures in the primary reaction zone. This gives plasma systems several advantages from a system standpoint. The smaller gas flows in the primary reaction chamber make plasma processing a quiescent process, minimizing particulate entrainment and carryover, and thus TRU carryover, in the offgas. In addition, the smaller gas flows allow plasma systems and offgas systems to be smaller and more compact, potentially lowering capital costs and making glovebox design somewhat easier than for conventional thermal treatment systems.

The plasma furnace can process a wide variety of wastes, including wood, paper, cloth, plastics, metals, glass, rocks, soils, etc, which makes plasma processing a very versatile technology. Versatility is important because, in addition to TRU waste, RFP (and other DOE facilities) have other mixed waste streams that require treatment to be in compliance with the LDRs. Having a single process that can treat most of the waste generated onsite provides a significant advantage in permitting cost, treatment cost, and implementation schedule. The construction and permitting of a single plasma waste treatment system will be less expensive than multiple permitting and construction projects, while providing treatment capability for a wide range of wastes.

Thus, a plasma arc incineration process will not only be able to adequately treat a supercompacted waste form, but may also provide a solution to each of the issues involved in waste emplacement at WIPP discussed previously. Elimination of organics and metals from the waste will essentially eliminate gas generation in WIPP. Plasma processing will produce a waste form that will immobilize plutonium and other radioactive constituents, producing a high integrity final waste form that will resist leaching into the brine. In addition, the final waste form will conform to the RCRA LDRs. The residual product will also be easier to characterize, as it will be more homogeneous and easier to sample. Most importantly, if the waste is fully treated to the maximum extent practical, then the liability of disposal is reduced, if not eliminated.

TEST PLAN

A series of individual process runs will comprise a test that will be conducted to serve as a "proof-of-principle" demonstration of the use of high temperature plasma technology as a waste treatment process for supercompacted TRU waste. The test will be conducted using only noncontaminated, nonhazardous materials. The simulated waste materials will be packaged into drums and processed by a supercompactor to simulate the RFP waste. The test materials will be chosen such that a reasonable representation of RFP waste is obtained.

A study of RFP TRU waste revealed that the majority of waste that will be supercompacted at RFP falls into two categories, combustible waste and bulk metal waste. Thus, the test will be structured to demonstrate processing of each of these two types of waste categories. Not only will this give an indication of the ability of a plasma process to treat the majority of RFP TRU waste, but since these two types of waste encompass a wide range of physical characteristics (from noncombustible through highly combustible), it will demonstrate the versatility of a plasma system in handling different types of waste. The composition of materials that will comprise the simulated waste, based on RFP TRU waste data, is presented in Table I.

TABLE I

Waste Compositions That Will be Tested for Plasma Treatment

Combustible Waste		Metal Waste	
Item	Weight %	Item	Weight %
Plastic	35	Steel	55
Rubber	15	Aluminum	10
Paper	20	Cast Iron	10
Cloth	5	Copper	10
Wood	15	Plastic	7
Sorbent	10	Paper	2
		Sorbent	6

Test Objectives

The primary objective of the test is to demonstrate that it is feasible to introduce a range of waste materials into a high temperature plasma environment, and that the organic fraction of the waste material will combust and/or pyrolyze into gaseous constituents, and the residual inorganic materials will form a molten phase that can be removed from the plasma furnace and cooled into a solid final waste product. If these events occur, the test will be judged as a successful demonstration that the principle of plasma treatment of supercompacted waste is sound.

The main secondary objectives of the test are to demonstrate the ability of a plasma process to provide several of the more important postulated benefits detailed previously in this paper. Of these, the tests will demonstrate the ability of the plasma process to provide a high degree of destruction of organic materials in the waste form. The test will also demonstrate that the residual molten material will form two distinct phases, a metal phase and a slag phase, that can be separated into two final waste forms. In addition, the test will show that the residual solid products, metal and slag, form high integrity leach-resistant final waste forms.

There are several lesser secondary objectives of the test series that will be demonstrated to the extent practical. If possible, the test will provide for a measurement of the quantity of particulate entrained in the process offgas to demonstrate that plasma systems produce only small quantities of particulate. The test will also evaluate the possibility and practicality of using a surrogate material for plutonium, and, if feasible, will provide data on the partitioning of the surrogate between the metal and slag phase.

Recent testing of plasma processes has indicated that the formation of NOx in the offgas may have a detrimental impact on the process acceptability from an environmental standpoint. Therefore, another test objective will be to measure the levels of NOx formed as a result of processing the simulated compacted waste. Further, past efforts have shown that processing rates of organic materials in a plasma system can be effectively enhanced through the use of steam in the plasma reaction chamber. If feasible, this test will examine whether the use of steam can be beneficial in processing organic waste in a plasma system. Finally, testing will provide qualitative data on the characteristics of the residual slag, and determine if glass formers have to be considered as an additive in the slag.

Process Description

In a waste treatment system concept, the actual generation and use of the plasma is only one component of an overall process scheme, where each of the other components is just as important to accomplishing the requirements of proper waste treatment. This particular test will examine one particular plasma system configuration to evaluate that system's effectiveness for processing the waste streams under consideration. The plasma system that will be used to do the initial investigation is a plasma system test apparatus located at Plasma Energy Corporation (PEC), a plasma system manufacturer located in Raleigh, North Carolina. A schematic of the proposed process is shown in Fig. 1.

The heart of the system is the primary reaction vessel, where the plasma torch will be installed. The system will use a transferred DC arc plasma torch to provide the process heat. The compacted waste drums will be fed into the chamber, where the organic fraction will volatilize and partially combust. The residual materials (bulk metals, silica, alumina, etc.) will form a molten pool in the bottom of the vessel. Upon complete destruction of the organics and proper melting of the residuals, the chamber, which is mounted on a trunnion system, will be tilted and the molten material poured out into a mold.

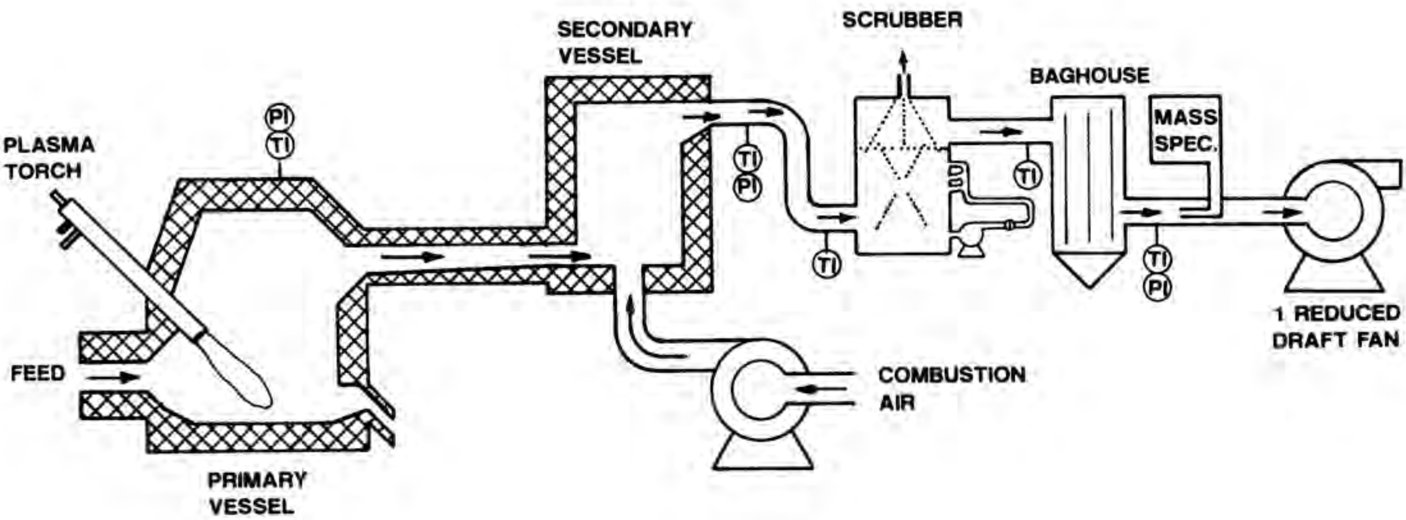

Fig. 1. Schematic of proposed plasma treatment process for supercompacted waste.

The volatilized/combusted products of the primary reaction will then be drawn from the primary chamber as offgas and fed into a secondary reaction vessel. The purpose of the secondary will be to complete the combustion reaction. Excess air (greater than stoichiometric requirements) will be introduced into the chamber and contacted with the process offgas to accomplish the combustion. This chamber is critical in assuring that hazardous organics are destroyed to the level required by RCRA regulations.

The process offgas from the secondary is drawn off and passed through an offgas treatment system. First, the offgas is introduced into a packed bed scrubber. This serves two functions; to remove heat from the offgas, and to remove particulate material and some of the acid gasses that may form depending on the composition of the test material (e.g. chlorinated compounds). Any remaining particulate entrained in the offgas is then filtered out by the use of a baghouse. An induced draft fan, located on the exit of the baghouse, promotes the flow of offgas in the system, and creates a slightly negative pressure in the primary chamber.

EXPECTED RESULTS

It is anticipated that the primary objective of the test will be accomplished. The simulated waste should be successfully introduced into the primary reaction chamber with only minor process upset. Both combustible and noncombustible waste should be adequately processed; that is the combustible fraction will be combusted or volatilized, and the remaining materials will form a melt that will be successfully poured from the vessel. The melt will cool to form a high integrity final from. This will demonstrate that the principle of plasma waste processing is sound.

The secondary objectives will further the notion of the effectiveness of plasma waste treatment. It is expected that the organic fraction of the simulated waste will essentially be completely destroyed, leaving little unburned carbon in the solidified final product and no large, unprocessed mass of material. The residual melt is expected to form the two distinct phases of slag and metal, that will be evidenced upon removal from the system. And lastly, the high integrity final waste forms will demonstrate excellent leachability characteristics, as measured by TCLP testing of the final products.

Some additional expected findings from the test will include: NOx will be formed in processing the simulated waste, however not in levels that should raise concern; limited or insignificant levels of particulate will be formed in the vessel and entrained in the process offgas (should particulate monitoring be feasible); and that the residual slag, depending on the simulated waste constituents, may require some glass additives to enhance its characteristics.

SUMMARY

At this time, DOE plans to dispose of its TRU waste at the WIPP facility in New Mexico without treating the waste first. Because of several factors, it is very possible that DOE may need to treat TRU waste prior to its ultimate disposal. Therefore, concurrent with its current program plan involving disposal of untreated waste, DOE must support the development of treatment alternatives applicable to TRU waste. The use of DC arc generated plasma technology as a waste treatment process is one of the more promising alternatives available for development. The results of a project to demonstrate the feasibility of using plasma technology as a waste treatment technology should in fact confirm that plasma is a leading candidate for development of a TRU waste treatment process.