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Microwave Technology for Waste Management Applications Including Disposition of Electronic Circuitry(U)

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DISCLAIMER

MICROWAVE TECHNOLOGY FOR WASTE MANAGEMENT APPLICATIONS INCLUDING DISPOSITION OF ELECTRONIC CIRCUITRY

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ABSTRACT

Microwave technology is being developed nationally and internationally for a variety of environmental remediation purposes. These efforts include treatment and destruction of a vast array of gaseous, liquid and solid hazardous wastes as well as subsequent immobilization of selected components. Microwave technology provides an important contribution to an arsenal of existing remediation methods that are designed to protect the public and environment from undesirable consequences of hazardous materials. Applications of microwave energy for environmental remediation will be discussed. Emphasized will be a newly developed microwave process designed to treat discarded electronic circuitry and reclaim the precious metals within for reuse.

INTRODUCTION

Significant quantities of hazardous wastes are generated from a multitude of processes and products in today's society. This waste inventory is not only very large and diverse, but is also growing at a disturbing rate and shows no signs of subsiding. In order to minimize dangers presented by constituents in these wastes, technologies are being investigated to minimize the waste generated and to provide safe handling, transportation, storage, disposal and destruction of hazardous components.

Microwave technology is being explored as one method to assist in remediation of these wastes. This includes development of a variety of microwave systems designed and tailored for a wide array of wastes and applications [1-5]. In the United States, waste remediation studies are being conducted primarily at Department of Energy installations. This includes Oak Ridge National Laboratory, Argonne National Laboratory, the Rocky Flats Plant, Los Alamos National Laboratory, and the Westinghouse Savannah River Site. Some of these programs represent joint undertakings with academia, such as the program at Savannah River being conducted with the University of Florida. International participants involved in microwave waste remediation efforts include the Geopolymer Institute in France and the Batelle Institut in Germany, Ontario Hydro's Research Division in Canada, Kobe Steel in Japan, and others.

There are many reasons for using microwave processing for waste remediation compared to other methods. In general, advantages of using microwave technology for waste remediation may include some or all of the following features listed in **Table 1**.

Table 1
Potential Advantages of Microwave Processing for
Waste Remediation

- Waste volume reduction
- Rapid heating
- High temperature capabilities
- Selective heating
- Enhanced chemical reactivity
- Ability to treat wastes in-situ
- Treatment or immobilization of hazardous components to meet regulatory requirements for storage, transportation or disposal
- Rapid and flexible process that can also be made remote
- Ease of control

- Process equipment availability, compactness, cost, maintainability
- Portability of equipment and process
- Reduction in personnel radiation exposure for rad wastes (ALARA)
- Energy savings
- Cleaner energy source compared to some more conventional systems
- Overall cost effectiveness/ savings

The advantages to be realized depend on many factors, especially the type and characteristics of the wastes or conditions to be treated.

MICROWAVE REMEDIATION APPLICATIONS

There are many types of hazardous wastes that are potential candidates for microwave treatment. Wastes currently under study and of special interest include radioactive wastes and sludges (high, low, and intermediate level wastes, transuranic and mixed wastes), contaminated soils and sediments, incinerator ashes, industrial wastes and sludges, medical and infectious wastes, asbestos, groundwaters, volatile organic compounds (VOC's), and discarded electronic circuitry. A variety of applications using microwave energy for treatment of these wastes are discussed in fine overview papers [1-5] and the reader is recommended to review these references for more detail. The following will be a brief discussion of some of the more interesting uses of microwave energy for waste remediation along with a more detailed discussion of using microwave energy for remediation of discarded electronic circuitry.

GASEOUS & LIQUID TREATMENTS

Microwave Induced Plasma Technology is being developed by Argonne National Laboratory and a Microwave Fluidized Bed Reactor by Los Alamos National Laboratory for destruction of volatile organic compounds or VOC's. Microwave energy is also being investigated for treatment of nitrogen oxide as well as a variety of other gaseous components.

• Destruction of Volatile Organic Compounds

Microwave induced plasma technology has the advantage of producing extremely high temperatures for selected waste management applications. Temperatures in excess of 10,000°C can be obtained if desired, although lower temperatures are used most often. Argonne National Laboratory has been involved with a microwave induced plasma reactor and environmental remediation efforts in a low temperature plasma range of less than 5,000°C [6]. In this application, trichlorethylene (TCE) or trichloroethane (TCA) in concentrations of 100-10,000 ppm have been fed into the plasma along with other constituents. Free electrons and radicals are then generated in the plasma and reactions are started which destroy the TCE or TCA and convert it into less noxious components. This conversion can be better than 99% effective. This technology is also believed to be applicable to many other multicomponent mixtures, including aromatic and aliphatic chlorinated compounds.

Los Alamos National Laboratory has investigated use of a microwave fluidized bed reactor to produce chemical oxidation reactions used for waste remediation [7,8]. In this process, microwave energy is used to selectively heat the surface of silicon carbide particles to about 500°C without heating reactor walls. This radiation also activates the silicon carbide surface to promote surface oxidation reactions. Work performed on trichloroethane-air mixtures has demonstrated as much as a 98% conversion of TCA.

• NO_x Reduction

Dow Chemical and the CHA Corporation have been studying NO_x reduction on Char using microwave energy [9]. There are millions of tons of nitrogen oxide (NO and NO_2) that are discharged to the air each year with the potential of contributing to acid rain and street level ozone. These are especially important considerations in large industrial areas of our country.

Existing NO_x abatement technologies are believed to be inadequate for long term needs. A form of coal, called Char, can absorb NO_x from waste gas and when microwave energy is used, can convert the NO_x and carbon to nitrogen and carbon dioxide via reduction.

Soils contaminated with toluene and xylene have been successfully decontaminated using microwave energy by University of Mississippi investigators.

- Toluene and Xylene

Toluene and xylene are used as organic solvents in many industrial synthesis processes. These aromatic hydrocarbons appear as hazardous contaminants in volatile organic compounds found in soil and groundwaters. Microwave energy has been used by Mississippi State University for decontaminating soils containing these contaminants [10]. The removal rate of toluene and xylene was seen to improve by simply adding water to the system, which generates additional heat when exposed to microwave radiation. With removal of these organic soil contaminants, contaminated soil could be disposed of safer, easier and more cost effectively in landfill disposal sites.

Microwave energy has also been used for removing liquids from waste mixtures by Ontario Hydro's Research Division of Canada. These efforts include solvent waste treatment for the automotive industry and dewatering of sludges existing in the nuclear field.

- Automotive Plastic Solvents

Instrument panels used in the automotive industry are made from ABS plastic, vinyl and polyurethane foam [1,11]. The machinery which produces these materials must be periodically cleaned, which produces a hazardous byproduct consisting of foam and the cleaning solvent, methylene chloride. The waste generated due to the cleaning operation is currently stored in drums.

Because the foam in the waste mixture is a good insulator, conventional electric resistance heating methods used to condense and recover the solvent in this mixture, and reduce the waste volume, were not effective. Because of the properties of the foam/ solvent waste mixture, microwave heating was examined. It was shown that the microwaves could selectively heat the solvent within the drum which quickly distilled the methylene chloride without overheating the foam. The treatment was successful and waste volume significantly reduced, which contributed to important cost savings.

- Dewatering of Low Level Nuclear Waste

Using a similar concept to the successful treatment of solvents used in the automotive industry, dewatering of low level nuclear waste in-situ was also examined [1,11]. Microwave energy was used to dewater the sludge in the same waste storage vessel that the waste was contained, which resulted in minimizing handling of the radioactive waste and reducing the waste volume by about 5%. The microwave treatment designed to dewater the low level radioactive sludge resulted in a product which met Canadian Atomic Energy Control Board acceptance criteria.

SOLID TREATMENTS

Microwave energy is being used for immobilization of hazardous inorganic and organic wastes. One of the most desired waste forms produced is glass, which has exhibited an outstanding ability to retain hazardous components under adverse conditions and for long periods of time [12, 13]. There have been a variety of waste glass forms produced using a vast array of waste compositions. These glass products meet regulatory requirements and possess excellent chemical durability, mechanical integrity as well as good thermal and radiation stability. In addition to glass, other waste forms such as cementious products have been produced using microwave energy.

• Vitrification of Inorganic Wastes

Since 1985, microwave technology has been under investigation and development at the Rocky Flats Plant in Golden, CO. Initial efforts involved using microwave energy to simply dry sludge. The technology then progressed into a larger effort involving using microwave energy to treat and solidify a variety of hazardous and radioactive wastes.

In the Rocky Flats process, microwave energy is used to melt waste contained inside 30-gallon drums [14,15]. A waveguide directs the energy from a 60 kilowatt, 915 megahertz microwave generator to the drum, which heats its contents to about 1000°C, thus melting the inside material. After melting is initiated on a small waste batch, the remaining waste is then continuously feed into the drum which will ultimately contain about 300 kilograms of melted waste. The most significant advantage of this technology compared to other means is that very significant volume reductions can be obtained (~80%) which translates into significant storage and disposal cost savings. In addition, the waste glass produced from the microwave vitrification process meets current transportation and disposal regulations. Wastes of interest to the Rocky Flats site include hydroxide precipitation sludge, nuclear storage tank materials, ash and soil. This technology has already been demonstrated on a laboratory scale, pilot plant scale and most recently, a full-scale demonstration unit which is now operable. The technology is believed to be applicable to most solid, inorganic waste compositions.

• Incinerator/ Microwave Treatment of Plutonium

Plutonium-contaminated solid wastes are generated during mixed oxide (MOX) fuel fabrication. A process has been developed by Kobe Steel, Ltd. for treatment of this waste at the Tokai Works of the Power Reactor and Nuclear Fuel Development Corporation (PNC) of Japan [16, 17]. The process uses an incinerator coupled with a microwave unit. The waste is initially incinerated and resulting ash fed into an adjacent microwave melter where it is vitrified in a batch process. The system is relatively compact so that it may be contained within a glovebox which is necessary for safe processing, due to the radioactivity of the waste. A generator external to the glovebox, produces microwaves which are transmitted into the glovebox by a waveguide to conduct the melting operation. The waste is melted and vitrified in crucibles which serve as both the melting vessels as well as the ultimate storage vessels. This technology is being expanded to include treatment of liquids, sludges, asbestos, residues of acid digestion, concretes, contaminated soils and other radioactive waste compositions.

• Non-Radioactive Ash

The University of California and Los Alamos National Laboratory have been studying the melting and immobilization of non-radioactive ash using microwave energy [18]. The ash was mixed with additives and different waste loadings were studied. The composition of the ash was primarily silica, titania, calcia, alumina and carbon and the additives consisted of magnetite, lithium and sodium carbonate and boron oxide. Among the results noted was that melted samples with more than 30 wt. % additives had an undetectable leaching rate (< 0.1 ppm of lead).

• Cement Waste Forms

Geopolymers are also being examined for containment of radioactive and hazardous wastes by institutions including the Geopolymer Institute in France and the Batelle Institut in Germany [19]. Mineral Geopolymer materials are new cementitious materials with zeolitic properties developed by the Group of Companies "GEOPOLYMERE" in Europe. They are alkali-silico-aluminates. Microwave processing using commercial units has been used to produce rapidly a stable waterfree ceramic waste form to contain hazardous components.

• Concrete Decontamination by Microwave Spalling

Oak Ridge National Laboratory is developing a microwave spaller for decontaminating concrete currently present throughout the DOE complex [20]. The spaller uses microwaves to heat water absorbed in the outer layer of the concrete. This creates induced stresses which cause the surface to burst or spall off. A vacuum then collects the particles produced. This operation has the potential of producing less airborne dust than other techniques and less secondary waste.

DESTRUCTION OF ELECTRONIC CIRCUITRY AND RECLAMATION OF PRECIOUS METALS

INTRODUCTION

Microwave technology has been examined by the University of Florida and the Westinghouse Savannah River Technology Center to treat a variety of potentially hazardous materials and components [21,22]. One application of special interest is the destruction and vitrification of electronic components and recovery of important metals for reuse [23]. Advantages of this technology include simplicity of operation, significant waste volume reduction, and production and separation of metal and waste glass forms. The waste glass product produced ties up hazardous components and meets environmental leaching standards and the metal product formed allows precious and other metals to be conveniently reclaimed for recycling. The waste glass forms have also been successfully produced without the need of any additives.

BACKGROUND

Electronic components and circuits are indispensable parts of our society today and are vital components in a multitude of consumer products and services. For example, they can be found in a variety of "high-tech" systems such as medical life support equipment, computers, and automotive systems, as well as being vital parts of more "common-place" items such as telephones, TV's, ovens, refrigerators, blenders, as well as countless other products.

Each year, many of these products containing electronic circuitry are retired. Hence, millions and millions of electronic components and circuit boards must be disposed of in a cost effective and environmentally safe manner. At present, many consumer products containing electronic components are discarded in landfills throughout our nation. This results in a number of concerns. First, because of the very large volume of these materials, many landfills are now filling up, resulting in the need for new "dumps" or disposal sites and increased costs to all. Next, there are a variety of hazardous materials that can be contained within electronic components. In landfills, these elements can leach from the waste and make their way into groundwaters, which can result in undesirable public and environmental consequences. Finally, because the products are simply thrown away, there is no attempt to reclaim useful materials within the circuits and hence, natural resources in these wastes, including precious metals, are discarded and cannot be reused or recycled.

The University of Florida and the Savannah River Technology Center have investigated the use of "specialized" microwave technology for a variety of waste management applications. This effort was expanded into other related areas including weapons dismantlement activities and most recently, to destruction of electronic circuitry and reclamation of precious metals within.

The joint program involving laboratory-scale experiments have produced the following important results:

RESULTS

- A wide array of electronic components were able to be treated by a <u>relatively simple, 1-step, hybrid-heated microwave process</u>
- Actual <u>waste volume reductions of >50%</u> were achieved with geometric volume reductions significantly greater
- As a result of the controlled microwave process, important <u>metal components were readily separated</u> from waste glass

- A waste glass product was able to be fabricated without the use of any additives and the glass produced retained hazardous components and met important environmental leach standards
- Precious metals, including gold and silver, were separated effectively and reclaimed for reuse
- The entire process can be mocked-up to a larger scale and also made mobile.

This work, along with a unique tandem microwave waste remediation system, designed to not only treat electronic circuitry but also the off-gases produced, will be described in more detail at this symposium [24]. This system is depicted in **Figure 1** and in **Figure 2**, key operations involved in the destruction of the electronic components and reclamation of important metals are summarized.

Figure 1
Schematic Representation of the University of Florida/ Westinghouse Savannah River Technology Center Tandem Microwave Processing System (Ref. 24)

Figure 2
Steps in the Processing of Electronic Components Using Hybrid Microwave Heating (Ref. 24)

SYSTEMS APPROACH/ COMMERCIALIZATION CONSIDERATIONS

Considering the many potential advantages of using microwave energy for remediation of both radioactive and non-radioactive wastes, it may seem surprising to some that there are not more commercial systems in operation. There are two main reasons for the very slow adoption of microwave technology for waste remediation. First, the concept of "if it ain't broke, don't fix it" illustrates the difficulty of trying to replace existing and more conventional technology with new and mainly unproven methods. Second, most of the efforts of using microwave energy for treating hazardous wastes have been scattered and directed to very specific or niche markets. What is often lacking is an integrated systems approach, using interdisciplinary teams, to address the entire problem. An example of a "dream team" might include representatives from academia (technical leadership and support), a federal or national laboratory (engineering, systems and regulatory support, potential duel use definition of the technology, and financial support), microwave/ equipment manufacturer (mocking up/ tailoring of existing equipment for a potential new market), and the customer for the service (knowledge of the market place including production rates and product specifications, potential financial support, and profit motive driver). In the case of waste remediation, expertise in microwave technology alone is insufficient to move the technology into the commercial section. For example, for vitrification of hazardous wastes using microwave energy, knowledge of glass melting processes and chemistry is very important, analytical support and an understanding of regulatory requirements are needed, off-gas treatment and the ability to manage and show compliance of both primary and secondary wastes essential, and a market-type analysis is necessary to provide a cost incentive for the service. Until teams of this type and a systems approach is fully utilized, commercialization on a large scale will continue to be very slow.

SUMMARY

Microwave energy provides important potential advantages for remediation of a wide range of radioactive and non-radioactive hazardous wastes. It provides an important contribution to an already existing and growing arsenal of remediation technologies. However, before its potential can be fully recognized and ultimately commercialized, an interdisciplinary, integrated systems approach, would be beneficial.

REFERENCES

1 Oda, S.J., "Dielectric Processing of Hazardous Materials- Present and Future Opportunities", Microwave Processing of Materials IV, (M.F. Iskander, R.J. Lauf and R.L. Beatty, eds.), Materials Research Society, Vol. 347, pp. 371-382 (1994).

2 Oda, S.J., "Microwave Remediation of Hazardous Waste: A Review", Microwave Processing of Materials III, (R.L. Beatty, W.H. Sutton and M.F. Iskander, eds.), Materials Research Society, Vol. 269, pp. 453-464 (1992).

3 R.L. Schulz, D.C. Folz, D.E. Clark, R.M. Hutcheon and G.G. Wicks, "Applications of Microwave Energy for Waste Remediation", proceedings of the 28th Microwave Power Symposium, International Microwave Power Institute, Montreal, Canada (1993).

4 Krause, R.T. and Helt, J.E., "Applications of Microwave Radiation in Environmental Remediation Technologies", Microwaves: Theory and Application in Materials Processing II, Ceramic Transactions (D.E. Clark, W.R. Tinga and J.R. Laia, eds.), American Ceramic Society, Vol. 36, pp. 53-59 (1993).

5 Dauerman, L., Windgasse, G., Zhu, N. and He, Y., "Microwave Treatment of Hazardous Wastes: Physical Chemical Mechanisms", Microwave Processing of Materials III, (R.L. Beatty, W.H. Sutton and M.F. Iskander, eds.), Materials Research Society, Vol. 269, pp.465-469 (1992).

6 Krause, R.T. and Helt, J.E., "Chemical Detoxification of Trichlorethylene and 1,1,1 Trichloroethane in a Microwave Discharge Plasma Reactor at Atmospheric Pressure", Emerging Technologies in Hazardous Waste Management III, American Chemical Society (D.W. Tedder and F.G. Pohland, eds.), No. 518, pp. 393-410 (1993).

7 Varma, R., Nandi, S.P. and Katz, J.D., "Detoxification of Hazardous Waste Streams Using Microwave-Assisted Fluid-Bed Oxidation", Microwave Processing of Materials II, (W.B. Snyder Jr., W.H. Sutton, M.J. Iskander and D.L. Hohnson, eds.), Materials Research Society, Vol. 189, pp.67-68 (1991).

8 Varma, R. and Nandi, "Oxidation Degradation of Trichloroethylene Absorbed on Active Carbons: Use of Microwave Energy", Microwaves: Theory and Application in Materials Processing, Ceramic Transactions (D.E. Clark, F.D. Gac and W.H. Sutton, eds.), American Ceramic Society, Vol. 21, pp. 467-73 (1991).

9 Buenger, C.W., Pererson, E.R. and Cha, C.Y., "NO_x Reduction on Char Using Micrwoaves, Microwave Processing of Materials IV, (M.F. Iskander, R.J. Lauf and R.L. Beatty, eds.), Materials Research Society, Vol. 347, pp. 395-399 (1994).

10 George, C.E., Jun, I. and Fan J., "Application of Microwave Heating Techniques to the Detoxification of Contamiated Soils", Nuclear Waste Management IV, Ceramic Transactions (G.G. Wicks, D.F. Bickford and L.R. Bunnell, eds.), American Ceramic Society, Vol. 23, pp. 761-768 (1991).

11 Oda, S.J., "Microwave Applications to Process Nuclear and Hazardous Waste", Microwaves: Theory and Application in Materials Processing II, Ceramic Transactions

(D.E. Clark, W.R. Tinga and J.R. Laia, eds.), American Ceramic Society, Vol. 36, pp. 73-79 (1993).

12 Peterson, R.D., Johnson, A.J. and Swanson, S.D., "Application of Microwave Energy for Solidification of Transuranic Waste", Waste Management '88, Proceedings of Symposium on Waste Management (R.G. Post, ed.), pp. 325-330 (1988).

13 Peterson, R.D. and Johnson, "In-Drum Vitrification of Transuranic Waste Sludge Using Microwave Energy", Trans. Amer. Nucl. Soc., Vol. 60, pp. 132-133 (1989).

14 U.S. Environmental Protection Agency, Handbook- Vitrification Technology for Treatment of Hazardous and Radioactive Waste, EPA/625/R-92/002 (1992).

15 Wicks, G.G., "Nuclear Waste Glasses", Treatise on Materials Science and Technology, Glass IV, M. Tomozawa and R.H. Doremus, eds., Vol. 26, pp. 57-118 Academic Press, Inc. (1985).

16 Miyata, K., Ohuchi, J., Inada, E. and Tsunoda, N., "Incineration and Ash Melting for Plutonium-Contaminated Wastes at PWTF", presented at the Incineration Conference, Knoxville TN, May 1-5, (1989).

17 Ohuchi, M., Miyata, K., Ohuchi, J., Inada, E. and Tsunoda, N., "Melting of Pu-Contaminated Residues by Powering Microwave", Nuclear Waste Management III, Ceramic Transactions (G.B. Mellinger, ed.), American Ceramic Society, Vol. 9, pp. 113-121 (1990).

18 Morita, K., Nguyen, V.Q., Nakaoka, R., and Mackenzie, J.D., "Immobilization of Ash by Microwave Heating", Microwave Processing of Materials III, (R.L. Beatty, W.H. Sutton and M.F. Iskander, eds.), Materials Research Society, Vol. 269, pp.471-476 (1992).

19 Davidovits, J., Schmitt, R.E. and Friehmelt, V., "Microwave Processing of Geopolymer-Cement Based Waste Forms", Microwaves: Theory and Application in Materials Processing II, Ceramic Transactions (D.E. Clark, W.R. Tinga and J.R. Laia, eds.), American Ceramic Society, Vol. 36, pp. 61-72 (1993).

20 White, T.L, Grubb, R.G., Pugh, L.P. Foster, D. and Box, W.D. "Removal of Contaminated Concrete Surfaces by Microwave Heating- Phase I Results", Waste Management '92, Proceedings of the Symposium on Waste Management (R.G. Post, ed.) pp.745-748 (1992).

21 Schulz, R.L., Fathi, Z. and Clark, "Microwave Processing of Simulated Nuclear Waste Glass", Microwaves: Theory and Application in Materials Processing, Ceramic Transactions (D.E. Clark, F.D. Gac and W.H. Sutton, eds.), American Ceramic Society, Vol. 21, pp. 451-458 (1991).

22 Schulz, R.L., Clark, D.E., Hutcheon, R.M. and Wicks, G.G., "Microwave Processing of Simulated Nuclear Waste Glass II", Microwaves: Theory and Application in Materials Processing II, Ceramic Transactions (D.E. Clark, W.R. Tinga and J.R. Laia, eds.), American Ceramic Society, Vol. 36, pp. 89-97 (1993).

23 Schulz, R.L., Folz, D.C., Clark, D.E. and Wicks, G.G., "Microwave Destruction/ Vitrification of Electronic Components", Microwaves: Theory and Application in Materials Processing II, Ceramic Transactions (D.E. Clark, W.R. Tinga and J.R. Laia, eds.), American Ceramic Society, Vol. 36, pp. 81-88 (1993).

24 Schulz, R.L., Folz, D.C., Clark, D.E. and Wicks, G.G., "Microwave Treatment of Emissions from the Destruction of Electronic Circuitry", to be presented at the 97th ACerS Annual Meeting in the symposium on "Microwaves: Theory and Application in Materials Processing III" and to be published in the proceedings, Cincinnati OH, April 30-May 3 (1995).

F.G 1

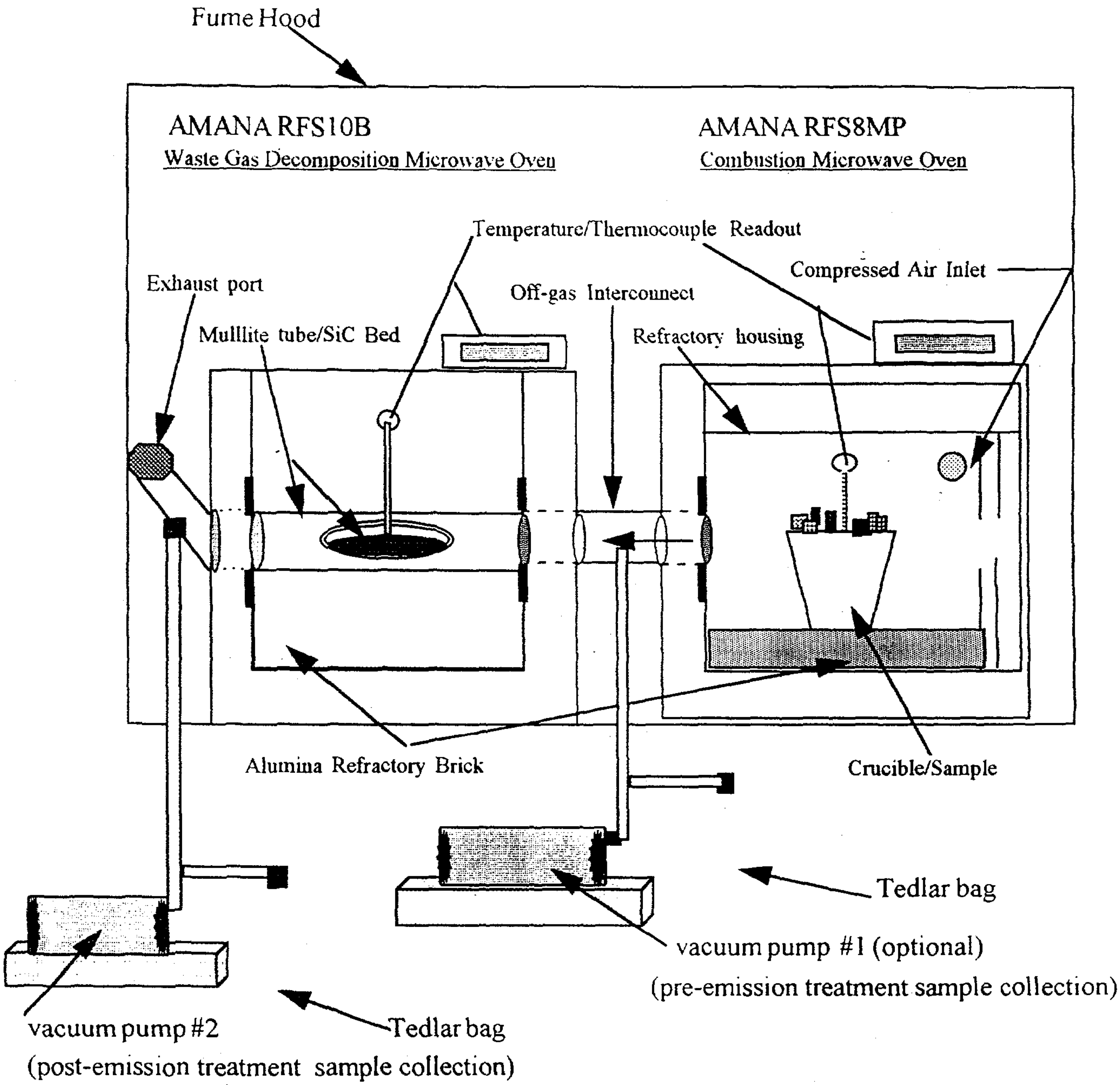
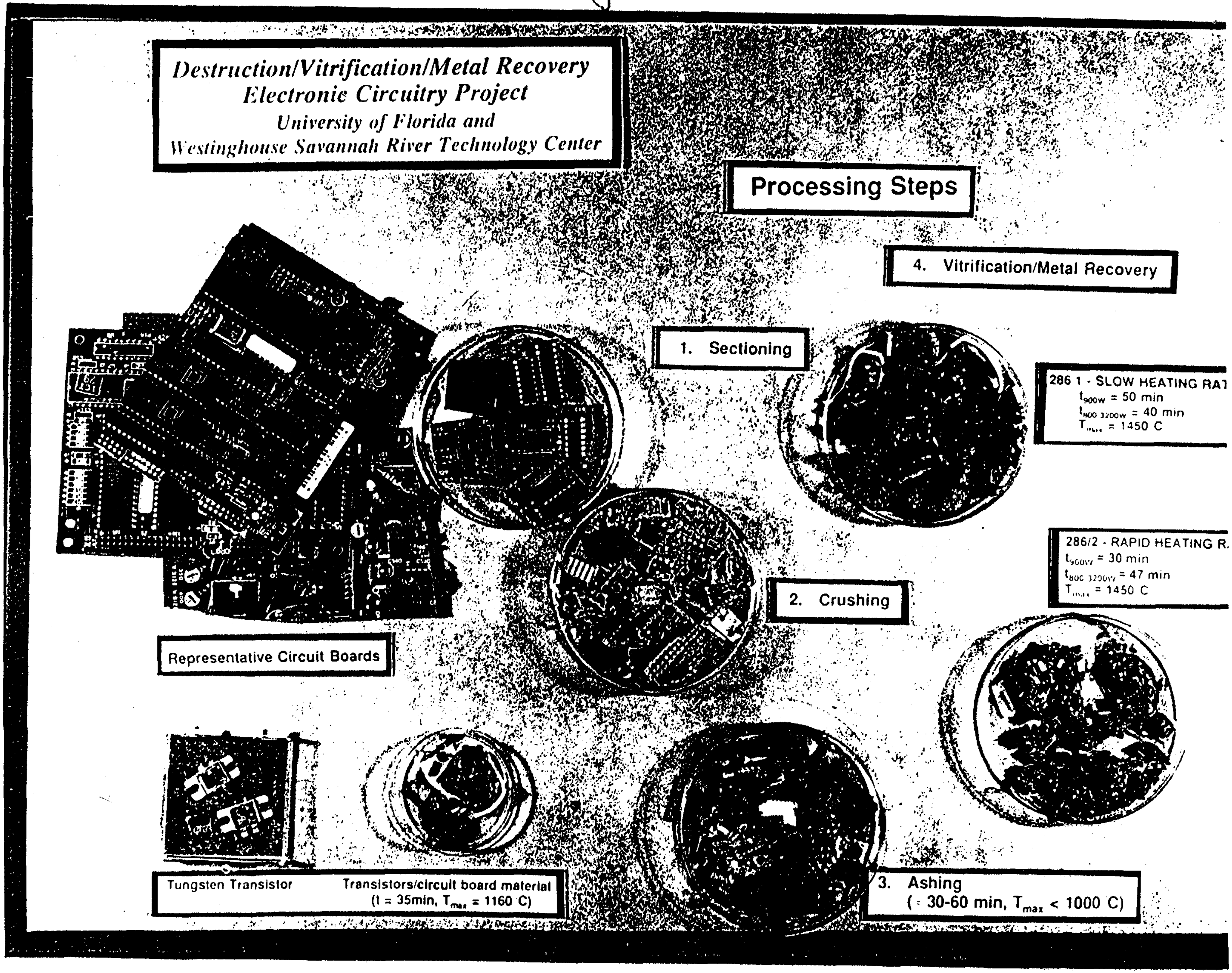

Fume Hood
AMANA RFS10B
Waste Gas Decomposition Microwave Oven
AMANA RFS8MP
Combustion Microwave Oven
Temperature/Thermocouple Readout
Compressed Air Inlet
Exhaust port
Off-gas Interconnect
Mulllite tube/SiC Bed
Refractory housing
Alumina Refractory Brick
Crucible/Sample
Tedlar bag
vacuum pump #1 (optional)
(pre-emission treatment sample collection)
vacuum pump #2
Tedlar bag
(post-emission treatment sample collection)

Fig 2


Destruction/Vitrification/Metal Recovery
Electronic Circuitry Project
University of Florida and
Westinghouse Savannah River Technology Center
Processing Steps
4. Vitrification/Metal Recovery
1. Sectioning
286/1 - SLOW HEATING RAT
t_{900W} = 50 min
$t_{800-3200W}$ = 40 min
T_{max} = 1450 C
286/2 - RAPID HEATING R
t_{900W} = 30 min
$t_{800-3200W}$ = 47 min
T_{max} = 1450 C
2. Crushing
Representative Circuit Boards
Tungsten Transistor
Transistors/circuit board material
(t = 35min, T_{max} = 1160 C)
3. Ashing
(≈ 30-60 min, T_{max} < 1000 C)