FINAL REPORT
FOR CRADA NO. C-01-03
BETWEEN
BROOKHAVEN SCIENCE ASSOCIATES
AND
ACCELERON, INC.

Project Entitled: Non-Vacuum Electron Beam Welding

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Final Report for CRADA No. BNL-01-03 Between BNL and Acceleron, Inc.

Abstract Original objectives of CRADA number BNL-01-03 between BNL and Acceleron, Inc., were to further develop the Plasma Window concept (a BNL invention covered by US Patent number 5,578,831), mate the Plasma Window to an existing electron beam welder to perform in-air electron beam welding, and mount the novel non-vacuum electron beam welder on a robot arm. Except for the last objective, all other goals were met or exceeded. Plasma Window design and operation was enhanced during the project, and it was successfully mated to a conventional 4 kW electron beam welder. Unprecedented high quality non-vacuum electron beam welding was demonstrated. Additionally, a new invention the Plasma Shield (US Patent number 7,075,030) that chemically and thermally shields a target object was set forth. Great interest in the new technology was shown by a number of industries and three arcs were sold for experimental use. However, the welding industry requested demonstration of high speed welding, which requires 100 kW electron beam welders. The cost of such a welder involved the need for additional funding. Therefore, some of the effort was directed towards Plasma Shield development. Although relatively a small portion of the R&D effort was spent on the Plasma Shield, some very encouraging results were obtained. In-air Plasma Shield was demonstrated. With only a partial shield, enhanced vacuum separation and cleaner welds were realized. And, electron beam propagation in atmosphere improved by a factor of about 3. Benefits to industry are the introduction of two new technologies. BNL benefited from licensing fee cash, from partial payment for employee salary, and from a new patent. In addition to financial benefits, a new technology for physics studies was developed. Recommendations for future work are to develop an under-water plasma shield, perform welding with high-power electron beams, carry out other plasma shielded electron beam and laser processes. Potential benefits from further R&D are that various processes involving electron ion and laser beams that have now restrictions can, with the Plasma Shield be performed in practically any environment. For example, electron beam and laser welding can be performed under water, as well as, in situ repair of ship and nuclear reactor components. The plasma shield results in both thermal (since the plasma is hotter than the environment) and chemical shielding. The latter feature brings about in-vacuum process purity out of vacuum, and the thermal shielding aspect results in higher production rates.

Attached is a very extensive report that was sent to DOE and to Connecticut Department of Environmental Protection

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Acceleron Electron Beam, LLC

Date: April 4, 2006

Re: Final Summary Report for the completion of DOE grant

Title: Non-Vacuum Electron Beam Welding

Contract No. U.S. Department of Energy Contract No. DE-AC02-98CH10886 under the NICE3 program.

OBJECTIVE: Acceleron Electron Beam, LLC will demonstrate plasma window enhanced Electron Beam Welding (EBW) at industrial scale production levels upon retrofitting the plasma window to an existing EBW column. BNL will collaborate with Acceleron Electron Beam, LLC in the technical aspects of the project including the construction of an approved beam column and plasma window.

Plasma Window Projection

NON-VACUUM ELECTRON BEAM WELDING

SECTION 2: Narrative

A. Brief Summary of the Original Project Goals

Original project goal was basically to develop a non-vacuum welding machine that possesses in-vacuum weld quality, while eliminating limitations and electrical consumptions associated with vacuum systems. Electron Beam Welding (EBW) has many advantages over other more common welding processes. EBW has high penetration; low distortion, precisely controllable and can join dissimilar metals at near parent metal strength without filler material. But, process efficiency is limited by the need to place the workpiece in a vacuum chamber, which must be evacuated for each operation. The continual use of large industrial vacuum pumps to evacuate the welding chamber is inefficient and wasteful; and, the chamber imposes a strict size limit on the workpiece. Current welding techniques used in large industrial applications often lack the desired quality. The electron beam, on the other hand, makes the highest quality welds available.

The development of a high quality non-vacuum EBW technology can positively impact numerous U.S. manufacturing sectors by reducing the cost and energy demands of the current process while fostering new, cost effective, higher quality manufacturing techniques.

Our approach was to use a Plasma Window (high temperature charged particles configured to function as a "window" between high and low pressure regions) that contains a small high vacuum region necessary for e-beam formation while being essentially transparent - allowing beam propagation into open air. The plasma window facilitates EBW on workpieces of unlimited size in less restrictive locations. Unlike existing in-atmosphere systems, which makes a lesser quality weld due to beam scattering, the plasma window actually focuses the e-beam as it exits the window, thus maintaining the high quality welding. The novel welder was to consist of a plasma window mounted on an electron beam welding column replacing the welding chamber.

The end technical result of the project was to demonstrate non-vacuum EBW, which is completely automated with a computerized control panel. In-air electron beam welding and machining was supposed to be used to fabricate the following products: tooling in special alloys, aircraft fuel filters, metallic filters for the pulp industry (drilling/EBM), aerospace combustion chambers, various heavy duty sensors and medical instruments for minimally-invasive surgery to name just a few.

Once the end technical result is achieved commercialization of the novel welder was to commence.

B. Variance from Project Goals

Shortly after initial in-air welding was demonstrated, attempts at commercialization began with focus on non-vacuum EBW. But, although interest in this new technology was shown, no serious purchasing attempts were made. The project has been a success where by we have achieved metallurgical acceptable welds in air utilizing the Plasma Window. We have also proved that we can weld with the assistance of the Plasma Window and reduce the amount of power consumption of a typical EB non vacuum machine by approximately 45%. But, at this point we have not been able to secure a system that is ready for commercialization. The two main outstanding goals prior to commercialization are:

1. To achieve full commercialization, high speed welding must be demonstrated, which requires a high-power electron beam welder. Since we do not have a high-power welder, full commercialization cannot be achieved with our present resources. The reason is that the highest welding speed achieved (with the plasma window operating in pure helium) was 20 inches per minute (IPM). Welder power in that case was 3 kW (20 mA, 150 kW electron beam). However, industry standard for non-vacuum EBW is in the range of 100 – 200 IPM and sometimes more! With the electron beam welder having a maximum power of 6 kW, on which the plasma window is mounted, these welding speeds are unreachable. Since welders used in industry have electron beam power levels of the order of 100 kW or higher, it became

apparent that no imminent sales to the welding industry are feasible.

2. We have not found a way to provide operating longevity to the plasma window. With its present design, there is still too much required maintenance on the unit to make it market ready. Until we can provide a unit that has longevity, commercialization is not possible.

Nevertheless at this point, the original technical results have been achieved.

Consequently, we focused our efforts on the Plasma Shield, which is a new technology. "Shielded Beam Delivery Apparatus and Method" which is pending a patent submitted by Brookhaven National Labs, docket no. BSA 02-23.

The Plasma Shield is a vortex-stabilized arc that is employed to shield beams and workpiece area of interaction from atmospheric or liquid environment. A vortex-stabilized arc is established between a beam generating device (laser, ion or electron gun) and the target object. The arc, which is composed of a pure noble gas (chemically inert), engulfs the interaction region and generates an outward flow, thus, shielding it from any surrounding liquids (water) or atmospheric gases. The vortex is composed of a sacrificial gas or liquid that swirls around and stabilizes the arc. In current art, many industrial processes like ion material modification by ion implantation, dry etching, and micro-fabrication, as well as, electron beam processing, like electron beam machining and electron beam melting is performed exclusively in vacuum, since electron guns, ion guns, their extractors and accelerators must be kept at a reasonably high vacuum, and since chemical interactions with atmospheric gases adversely affect various processes. Various processes involving electron ion and laser beams can, with the Plasma Shield be performed in practically any environment. For example, electron beam and laser welding can be performed under water, as well as, in situ repair of ship and nuclear reactor components. The plasma shield results in both thermal (since the plasma is hotter than the environment) and chemical shielding. The latter feature brings about in-vacuum process purity out of vacuum, and the thermal shielding aspect results in higher production rates.

C. Future Technology Requirements

It is clear that for the **US industry to become more competitive**, it needs among other things to **become more energy efficient** and make less use of precious resources i.e. electricity and water. An electron beam welder with a plasma window is more energy efficient than other electron beam welders by 41.5% to 47.4% (please see table in section E2). And, this welder does not utilize ground water for cooling.

However, lasers (**which are very inefficient**) perform most welding that could have been performed by the welder developed in this project. The largest user of lasers is the automobile industry, which switched to laser welding in the early 1990's. But, lasers are extremely inefficient energy wise: conversion of electricity to laser power is no more than 20% for gas lasers and only 2 – 3% for other lasers (like those used in welding). Additionally, a fraction of the laser power is reflected off metals rather than going into a weld. By comparison, more than 90% of electric power is converted to electron beam power in a typical electron beam gun. And, reflection from metal surfaces is not a problem as it is with lasers.

Developments made in this project can meet future technology requirements regarding energy saving. Although switching to this novel welder from laser welding seems prudent in times of raising energy cost, it will not happen without government funding. Laser welding was developed as part of the SDI program with government funding only! Consequently manufacturers of laser welders have incurred no R&D costs in the beginning stages. Their R&D efforts appear to be more in the areas of equipment and motion advancements more so than for energy efficiencies. Some manufacturers have claimed some improvements but they are still considerable less efficient than electron beam. As pointed out in our energy saving chart, we have improved EB energy efficiencies by more than 40%. With more time and funding we feel we can get even achieve greater results in the future. By switching

to the technology developed under this program, the largest energy savings could come from the automobile industry, which is now too battered to fund any R&D, or to embark on a large-scale switch of welders.

D. Technology Application and Results

In addition to achieving high quality electron beam welding in atmosphere, the project generated breakthrough physics results, especially in the area of self-pinched propagation of electron beams in atmosphere. The physics results were subject to a press release by the American Physical Society and numerous journal articles.

Above all, results from the project proved, in principle, that welding can be accomplished with high power efficiency. But, laser welders (very wasteful in power and energy) cost about \$300,000 each when looking at a machine that has a maximum penetration of approximately $5/32$ or .160, while EB welders cost about \$1,000,000 each (\$700,000 can still buy lots of electricity). Keep in mind that the EB machine is capable of much deeper weld penetrations than $5/32$. Please see comments in the section of economic competitiveness to expound on this subject matter further.

To proliferate this technology, government R&D funding to develop fully automated EB welders with plasma windows on a robots arm is needed. This will level the field with laser welders. It will reduce EB welder cost to that of lasers and provide industry incentives to switch to energy efficient higher quality EB welders.

E. Updated Metrics

1 Definition of Typical Industrial Unit

Plasma Arc Window e-beam welder schematic

Plasma Arc Window detail

To generate an electron beam, a cathode of tungsten alloy is electrically heated to about 4,500°F. The cathode is held at a voltage potential between 90 and 150 kV relative to an anode at ground potential. Electrons come off the cathode surface and accelerate toward and through the anode, the amount of which is controlled by a bias voltage. Magnetic coils then focus the electrons into a narrow beam.

2 Energy Savings**ACCELERON** LLC

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1/18/2006

ELECTRON BEAM WELDER POWER COMPARISON :**Non-Vacuum - High Vacuum - Plasma Window EBW-NV**

Machine Type:	Non-Vacuum Welder	High Vacuum Welder	Plasma Window EBW-NV
General circuits, controls, and drives:	2.8 KW	2.8 KW	2.8 KW
High Voltage supply:	6.0 KW	6.0 KW	6.0 KW
Filament and Bias supply:	0.6 KW	0.6 KW	0.6 KW
Arc D.C. supplies (3):	N/A	N/A	7.6 KW
Holding pump:	1.6 KW	3.2 KW	N/A
Diffusion pump ('s):	2.2 KW	14.2 KW	N/A
Turbo pump:	N/A	N/A	0.7 KW
Mechanical roughing / blower pumps (2):	19.6 KW	9.8 KW	N/A
Tri scroll pumps (2):	N/A	N/A	1.5 KW
Total Power Consumption	32.8 KW	36.6 KW	19.2 KW

Comparison:**41.5% power savings running the Plasma Window system verses a Non-Vacuum welder****47.4% power savings running the Plasma Window system verses a High Vacuum welder**

Note: This comparison uses current measured, while the systems were running, to calculate K.W. usage. Previous comparisons used motor nameplate FLA (full load amperage) ratings.

3 Environmental Benefits

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3/24/2006

ELECTRON BEAM WELDER WASTE COMPARISON :

Non-Vacuum - High Vacuum - Plasma Window EBW-NV

Waste Type:	Non-Vacuum Welder		High Vacuum Welder		Plasma Window EBW-NV	
	Usage per Year		Usage per Year		Usage per Year	
	Usage	Dispose	Usage	Dispose	Usage	Dispose
Roughing Pump Oil:	56 gal	48 gal	28 gal	24 gal	N/A	N/A
Diffusion Pump Oil:	.35 gal	.25 gal	1.75 gal	1.25 gal	N/A	N/A
Holding Pump Oil:	1 gal	.8 gal	2 gal	1.6 gal	N/A	N/A
Total Oil Used	57 gal	49 gal	31 gal	27 gal	N/A	N/A
Cost Comparison	\$973		\$1,156		\$ 0	

Comparison:

\$ 973.00 yearly oil use savings running the Plasma Window system verses a Non-Vacuum welder

\$ 1,156.00 yearly oil savings running the Plasma Window system verses a High Vacuum welder

Note: This comparison is based on current prices to purchase and dispose of oil. Acceleron's preventative maintenance program schedules changing the mechanical pump oil every six months, and the diffusion pump oil once per year.

With this technology there is no pump oil that is required. It can eliminate the need for pump oil (and its disposal). Additionally, no ground water or electricity is needed for cooling these pumps.

4 **Economic Competitiveness**

At this stage we have not performed an in depth economic competitiveness. There is however a proven and measured cost savings in electricity, oil consumption and oil disposal as described in our report. There are many more items to consider when looking at its full cost effectiveness and in addition, the time at which it is measured is as important to take into consideration things such as technology advancements, cost of equipment, cost of consumables, electricity, other government mandates that may be instituted etc.

EB Equipment considerations: electricity costs, the elimination of the vacuum chamber cost, the elimination of roughing and diffusion pump costs, the elimination of required floor space, the elimination in maintenance costs, the elimination of additional electric costs due to heat being given off with roughing and diffusion pump, eliminating oil and oil disposal costs etc.

Laser Equipment consideration: They are considerably less energy efficient than present electron beam machines, but some manufacturers are beginning to make some advancements in this area. There are some large disparities when considering the manufacturer and the type of equipment CO2 or CW YAG. I.E. one laser manufacturer cost for a 1000W CW YAG is approx. \$240,000, another manufacturer is \$120,000. Additional costs to consider is the addition of CNC and what type of motion system does your application require. Before comparing laser to the Plasma Window for equipment and energy cost comparisons, there are many questions that need to be answered. Application requirement will dictate what equipment is necessary for a particular application. This will dictate energy use, cost of equipment, cost of operating the equipment per hour, payback etc.

5 **Productivity Enhancement**

Not applicable, device is still under development.

F. Technical Transfer Activities: Planed and Accomplished

Plasma window utilization for electron beam welding, drilling, and wire feed is still under negotiation, no technical transfer accomplishments to date.

Plasma window units were sold to CCRE and to NRL for other applications.

Acceleron Electron Beam, LLC and Brookhaven National Laboratories have a patent pending for the "Shielded Beam Delivery Apparatus and Method" docket no. BSA 02-23, Request No. 2087.

Networking to transfer technology: Presently Acceleron Electron Beam, LLC and Keystone Synergistic Enterprises, Inc. are nearing the completion of a working agreement where by Keystone will be responsible to search for outside interests and funding for the completion of the Plasma Window development and commercialization of the end product. Keystone was instrumental as the acting liaison between Acceleron Electron Beam, LLC and Southern Methodist University (SMU) to submit the following proposal to the National Science Foundation. Please review the proposal below.

Keystone founders are:

Bryant Walker is President and co-founder of Keystone Synergistic Enterprises, Inc. Keystone strives to provide their customers with new business development and aerospace materials processing and manufacturing technology improvement; including strategic planning, technology readiness assessments, and tactical implementation planning and execution.

Raymond Walker is Vice President and cofounder of Keystone Synergistic Enterprises, Inc., and President of ARGO Enterprise Technologies, Inc., technology consulting and specialists in economic and value stream analysis for manufacturing and service processes, and strategic growth planning.

Project:	"Development of Plasma Shielding Instrumentation Enabling Electron Beam Materials Processing in Air"
PI:	Radovan Kovacevic
Agency:	NSF, Major Research Instrumentation Program (MRI)
Duration:	36 months
Starting Date:	August 1, 2006
Deadline for Submission:	January 26 th , 2006

2. Project Summary

The main objective of this proposal is to develop novel metal joining and deposition equipment based on an electron beam (e-beam) shielded by plasma arc, or so-called "Plasma Arc Window", enabling electron beam processing to be performed in air. In the last few years, there has been an attempt at several research sites to show the benefits of using electron beam as a heat source in direct metal deposition. The main application of high power e-beam is for welding without using consumables. However, if the e-beam welding system is equipped with an adequate wire feeder and a computer controlled multi-axis positioning system, such a system could be used for the direct metal deposition (DMD) process. E-beam DMD uses a focused electron beam to create a molten pool on a metallic substrate. The beam is translated with respect to the surface of the substrate and metal wire is fed into the molten pool and the 3D build ups are thus made in a layered-additive fashion. The selection of an e-beam DMD process over the currently commercially available laser-based DMD systems is a logical choice, because of the ability of the e-beam DMD process to provide higher efficiency, excellent controllability, more versatility, and better quality of deposits. The quest for a new deposition technology is further emphasized after the bankruptcy of Aeromet Co. in 2005, as one of the largest users of laser-based additive manufacturing of aircraft components made of Ti-alloys.

The main drawback and limitation of using electron beam for high quality welding and direct metal deposition is the requirement to perform e-beam material processing in a vacuum. This requirement automatically limits the production rate and the size of the workpiece. However, in order to economically apply an electron beam for material processing, the processing has to be performed in an open atmosphere. It is possible to transmit the electron beam to the atmosphere through differential pumping section or foils; however, such systems rely on bulky, energy-hungry vacuum pumps to maintain the pressure differential between the source of electrons and the work piece. Due to electron beam degradation in differentially pumped sections (or foils), the non-vacuum electron beam welding/deposition process is not attributed with all of the advantages that characterize electron beam processing in a vacuum. In order to rectify the shortcomings of the present day vacuum-atmosphere interface done through differentially pumped chambers and orifices, or thin walls, we are proposing to develop novel metal joining and deposition equipment based on an electron beam shielded by the plasma arc, or by a so-called "Plasma Arc Window", which is patented by the Brookhaven National Laboratory.

The PI in cooperation with Dr. Ady Hershcovitch, a physicist at the Brookhaven National Laboratory, Upton, NY, Acceleron, Inc, East Granby, CT, and Keystone Synergistic Enterprises, Inc., Palm City, FL will work on the development of an electron beam welding/deposition machine capable of providing high quality material processing in air. The topic of this project is in direct relationship

with the main research thrust area of the newly established Industry/University Cooperative Research Center for Lasers and Plasma for Advanced Manufacturing at SMU, whose corporate members are: the Army Research Laboratory, General Motors, Lockheed Martin Missiles and Fire Control, Halliburton Energy Services, and Bell Helicopter.

Intellectual Merit and Broader Impacts:

The Plasma Window is a novel apparatus that utilizes a stabilized plasma arc as an interface between a vacuum and the atmosphere or pressurized targets without a solid material barrier. In addition to sustaining a vacuum/atmosphere interface, the plasma has a lensing effect on charged particles. The plasma current generates an azimuthal magnetic field, which exerts a radial Lorentz force on charged particles moving parallel to the current channel. With a proper orientation of the current direction, the Lorentz force is radially inward. This feature can be used to focus the electron beam to a very small spot size and to overcome the beam dispersion due to scattering by atmospheric atoms and molecules. The arc can be extended through air and/or water and can be projected onto a target to form a "Plasma Shield" which facilitates the shielding of metal joining and deposition in-air and underwater (or other hostile environments). The development of the proposed equipment will enable the PI to introduce new directions in research, training and education related to the physics of plasma, materials science, sensing, control, and automation that will be encountered in e-beam materials processing in air. If the project is successful, it will provide an unparallel deposition technology for the program entitled "Development of the Direct Digital Manufacturing" launched in September of 2005 under the Next Generation Manufacturing Technology Initiative as well as the additive and direct manufacturing by metal deposition programs sponsored by the Air Force Research Laboratory at Wright-Patterson Air Force Base.

The PI will work with the Director of the Minority and Women Engineering program, as well as with Paul Quinn College, Dallas, TX in order to attract more female and minority students into SMU's graduate engineering program. We plan to request NSF REU and RET supplements to the current NSF awards. We are going to participate very aggressively in achieving the goals of the recently founded Institute for Engineering Program at SMU. The federal government has been helping SMU to launch a national institute that will promote engineering from kindergarten through high school. Dissemination of the project's R&D results will be done through journal publications, conference presentations, seminars, website, as well as through graduate and undergraduate courses.

Other interested groups and markets are: Advanced Manufacturing Methods. Primary interests in the Advanced Manufacturing Methods are from NASA, Air Force, Edison Welding Institute, Wentgate Dyna Weld Inc. and Boeing. In addition recently Multidimensional Imaging, Inc. has shown interest for implementation in a practical medical X-ray source configuration.

G. Market Penetration Estimates

Until product/technology is fully developed we don't have a complete understanding of its full potential. I.E. as stated above with **Other interested groups and markets**, along with this technology having many other potentials including possible technology break thru and advancements in some of the markets stated below.

SCIENTIFIC APPLICATIONS FOR PLASMA WINDOWS

- ☞ **Window for 1 A, 1 MeV E-Beam for gas heating in hypersonic wind tunnel.**
- ☞ **Windowless gas targets (but with plasma windows) for fast (fusion) neutron generation (neutron sources for neutron tomography).**
- ☞ **Windowless beamlines for transmission of synchrotron radiation.** Plasma windows offer many advantages over presently-used beryllium windows: **radiation** passes through the window **unaffected**. A plasma window **cannot be damaged by radiation**. UV filter for rejection of 'high-order' light is of significant benefit to experiments like threshold photoionization spectroscopy, where contamination even at the 10^{-4} harmonic content can obscure the features of the spectrum of interest. X-ray microscopy, since it is free from the attenuation and spatial structure that attend the use of conventional window materials (e.g. beryllium or SiN), i.e., no scratches.
- ☞ **Spallation Neutron Source (SNS).** To replace various solid windows with cooling problem, as well as, neutron instrumentation windows.
- ☞ **APT- tritium production by accelerator.** Solid windows limit output.
- ☞ **Windows for high power x-ray source (DARHT).**
- ☞ **Internal (gas or plasma) targets, strippers, lenses in storage rings.** A plasma stripper/lens or an internal gas target "sandwiched" between two plasma windows. **Examples:** BNCT based on recirculating proton beams can be realized with two plasma windows on either side of a lithium cell. Plasma windows offer the only viable scheme for maintaining a highly-localized, high pressure, lithium vapor cell inside a high energy proton storage ring. Various internal targets (spin polarized in

RHIC), a plasma stripper/lens could enhance the stripping of heavy ions between the Booster and AGS, as well as between the tandem Van de Graaff and the Booster.

☞ **Fast acting valves in UHV beamlines.** In case of vacuum breach, plasmas can be ignited faster than mechanical valves without damage to beamline (unlike, presently used, misc. spring loaded shutters).

POTENTIAL AND EXISTING COMMERCIAL APPLICATIONS/MARKETS FOR PLASMA WINDOWS

I Non-vacuum electron beam welding With plasma windows, differentially pumped chambers and orifices, or thin walls, are replaced by a short high pressure arc, which also focuses the beams to overcome limitations, among which are low production rates due to required pumping time, limits on the size of target objects, and degradation of electron beams in foils or differentially pumped sections. Technological breakthroughs potentials (e.g., welding of double hull ships). Potential clients: ship builders, automotive.

I Under water (and other corrosive and hostile environments) **Electron Beam, Laser, & Ion Beam processes** with the plasma shield, in which plasma displaces fluids from (and engulfs) the work area, thus creating a "plasma shield" that isolates that area thermally and chemically (with noble gas plasma).

I Electron Beam material treatment.

I Non-vacuum material modifications by ion implantation, and dry etching, or micro-fabrication Presently performed only in vacuum, since ion beams at energies used in these applications are completely attenuated by foils and by long differentially pumped sections. Potentially very large yet unexplored market.

I Electron beam melting for manufacturing alloys is performed at a pressure of about 10^{-2} Torr. A major drawback of operating at this pressure range is the loss of elements with low vapor pressure. Consequently, it is desirable to raise the operating pressure to a higher level. Interested company.

I Electron beam generation of photo-neutrons for the production of medical isotopes. A 40 MeV electron beam strikes a W target. Resultant radiation can dislodge a neutron (via a giant resonance) to create a new element. One particular isotope is **Tc-99 (Technetium)**, which is presently used for 10 Million medical procedures in the US alone. Its half-life is only six hours, and it radiates enough energy to scintillate a scanner, but not enough to damage tissues. Presently, Tc-99 is made from Moly-100 in weapons-grade nuclear reactor, where a reactor neutron dislodges a Moly neutron to create a Moly-99, which subsequently decays to Tc-99. This process is expensive and it is monopolized. The

presently pursued electron beam alternative is very limited; since the W target is in vacuum where poor cooling sets a lower limit on the electron beam spot. With a plasma window, the target can be in the air, sufficiently cooled to absorb an intense electron beam to generate photo-neutrons. A number of companies, which make medical accelerators, will be interested in plasma windows. Seems like a large commercial potential.

I Windowless gas targets (but with plasma windows) **for fast neutron radiography to detect nitrogen (weapons) and carbon (diamonds), as well as for other forms of neutron tomography and therapy (BNCT).** Some commercial potential.

I Radioactive waste transmutation. Project at Los Alamos: proton are accelerated to 2 GeV unto a heavy metal target in air. Resultant 2-8 MeV spallation neutrons reduce radioactive waste. Presently, windows limit proton output. SNS to be built.

I Hardening of airplane wings and spacecraft parts with neutrons (or by implanting other ions)?

I Windows for high power lasers (especially high-pressure gas lasers).

H. Final Cost Sharing Information

Final Cost Sharing Information:

#	Company Name	Company Type	In-Kind Contribution	Cash Contribution	Total
1	DOE	state agency	\$ -	\$ 462,471.19	\$ 462,471.19
2	CL&P	utility	\$ -	\$ 218,000.00	\$ 218,000.00
3	Acceleron Inc	small business	\$ 1,111,586.95	\$ 105,316.21	\$ 1,216,903.16
		Grand Totals	\$ 1,111,586.95	\$ 785,787.40	\$ 1,897,374.35

I. List of Partners, Contractors, and their Respective Roles

#	Company Name	Company Contact	Address	City	State
1	D.E.P.	Lynn Stoddard	79 Elm St.	Hartford	CT
2	CL&P	Sam Fankhauser	PO Box 270	Hartford	CT
3	Brookhaven National Lab	Ady Hershcovitch	Bldg 911C	Upton	NY
4	Brookhaven National Lab	Margaret Bogosian	Bldg 475	Upton	NY
5	Acceleron Inc	Don Christensen	21 Lordship Rd	East Granby	CT
6	Acceleron Inc	Rory Montano	21 Lordship Rd	East Granby	CT
7	A.V.T.	Jim Capazzi	17 Ct Drive	East Granby	CT
8	A.V.T.	Gary Lachapelle	17 Ct Drive	East Granby	CT
9	Creve Coeur Research & Engineering	John Mullan	3127 Creve Coeur Mill Rd	St. Louis	MO
10	Naval Research Laboratory	Dr. Roger Meger	4555 Overlook Ave SW	Washington	DC

#	Company Name	Zip	Phone	Fax	e:mail
1	D.E.P.	06106	860-424-3236	860-424-4081	lynn.stoddard@po.state.ct.us
2	CL&P	06141	860-832-4750	860-832-4700	fankhsr@nu.com
3	Brookhaven National Lab	11973	631-344-4531	631-344-5954	herschcovitch@bnl.gov
4	Brookhaven National Lab	11973	631-344-7338	631-344-3729	bogosian@bnl.gov
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6	Acceleron Inc	06026	860-651-9333	860-651-5881	rmontano@acceleroninc.com
7	A.V.T.	06026	860-653-4176	860-653-3095	jiimc@advactec.com
8	A.V.T.	06026	860-653-4176	860-653-3095	gary007@cox.net
9	Creve Coeur Research & Engineering	63146	314-542-0800	314-542-0896	jmullan@ccrecomp.com
10	Naval Research Laboratory	20375	202-767-332	202-767-3553	meger@nrl.navy.mil

Lynn Stoddard is the funding administrator for the DOE grant administered by the Connecticut Department of Environmental Protection. .

Sam Fankhauser is the funding administrator for the Conservation Fund grant administered by CL&P.

Dr. Ady Hershcovitch is the inventor and project physicist for the Plasma Window project.

Margaret Bogosian is the manager of Intellectual Property & Industrial Partnerships for Brookhaven National Laboratories.

Don Christensen is the General Manager of Acceleron Electron Beam, LLC

Rory Montano is the President of Acceleron Electron Beam, LLC

Jim Capazzi is the President of AVT and was used as a consultant when required.

Gary Lachapelle is an outside contractor for AVT and was also hired as an outside consultant for a period of time.

John Mullan, President of CCRE is a customer who purchased a Plasma Window unit in January of 2003.

Dr. Robert Meger is employed by the Naval Research Laboratory; this customer also purchased a Plasma Window unit in April of 2005.

SECTION 3: Supplemental Information

- Plasma Window Presentation CD
- Weld analysis of 3 separate welds made with the Plasma Window 2-28-06
- Weld analysis of 1 weld made with the Plasma Window 6-10-05
- Letter from Tom Eagar of MIT, evaluation of in and out of vacuum weld samples

Quali-Tech, Inc.

MATERIALS ANALYSIS LABORATORY

REPORT NUMBER: 06-15743

DATE: February 28, 2006

PREPARED FOR: Mr. Rory Montano
ACCELERON, LLC
21 Lordship Road
East Granby, CT 06026

P.O. NUMBER: 22597RM

SUBJECT: Three (3) Weld Samples

ANALYTICAL TECHNIQUES: Scanning Electron Microscopy (SEM)
Energy Dispersive X-Ray Spectroscopy (EDS)
Optical Microscopy (OM)
Microhardness Testing

PURPOSE OF ANALYSIS

Examination of weld microstructure, hardness, composition and weld parameters.

RESULTS

The as-received weld cross-sections were examined optically at 10X and 100X. The welds on all samples showed good adhesion with no cracks or porosity (M-1 through M-14). The weld widths and heights are presented in Table I.

The hardness was determined in five locations across the weld (M-15). The results are presented in Table II. The composition was determined in the same location (Table III).

The surface oxide thicknesses were found to be:

<u>SAMPLE/SURFACE</u>	<u>OXIDE THICKNESS, MICRONS</u>
1 - Top	Less Than 1.0 (M-16)
1 - Bottom	Less Than 1.0 (M-17)
2 - Top	3.0 (M-18)
3 - Top	Less Than 1.0 (M-19)
3 - Bottom	Less Than 1.0 (M-20)

John J. Sabo, Lab Manager

JJS:jtb

Enclosures: Tables I Through III
Twenty Micrographs (M-1 Through M-20)
Returned Samples

2-13-06

Plasma Window Weld Sample Testing

Re: These are the parameters used for the 3 sample pieces that were analyzed by Quali-Tech, their report # 06-15743 dated February 28, 2006.

Sample # 1

Welded on 1-12-06

With Vortex configuration, partial plasma projection

150Kv, 32ma, 10ipm, 4psi..240 work distance from face of Plasma Window to work piece.

No cover gas at top of weld, small amount of bottom cover gas. Argon only

Material – 316 SS .125 thick.

.100% penetration, positive top bead with positive bottom bead.

Sample #2

Welded on 1-12-06

With Vortex configuration, partial plasma projection

150Kv, 30ma, 20ipm, 4psi.

Used .035 dia. wire at top of weld

.240 work distance from face of Plasma Window to top of work piece.

No cover gas at top of weld, small amount of bottom cover gas. Argon only

Material – 316 SS .125 thick.

Partial penetration, positive top weld bead.

Sample #3

Welded on 1-14-06

With Vortex configuration, partial plasma projection

150Kv, 30ma, 10ipm, 4psi..240 work distance from face of Plasma Window to work piece.

No cover gas at top of weld, small amount of bottom cover gas. Argon only

Material – 316 SS .125 thick.

.100% penetration, positive top bead with flush bottom bead.

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TABLE I

<u>WELD PARAMETER</u>	<u>SIZE, INCH</u>
1 - Top Weld Bead	0.012 Above Parent Material Surface
Top Bead Weld Width	0.0122
Bottom Bead	0.007 Positive Under Bead
Bottom Bead Weld Width	0.128
Overall Weld Height	0.149
Depth of Weld	100% of .130 Thickness
Weld Width Half the Distance of Weld Penetration	0.082
2 - Top Weld Bead	0.021 Above Parent Material Surface
Top Bead Weld Width	0.093
Overall Weld Height	0.093
Depth of Weld	0.070
Weld Width Half the Distance of Weld Penetration	0.069
3 - Top Weld Bead	0.016 Above Parent Material Surface
Top Weld Width	0.107
Bottom Bead	0.003 Positive Under Bead
Bottom Bead Weld Width	0.087
Overall Weld Height	0.125
Depth of Weld	100% of .120 Thickness
Weld Width Half the Distance of Weld Penetration	0.076

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TABLE II

<u>SAMPLE/AREA</u>	<u>DPH</u>	<u>ROCKWELL EQUIVALENT</u>
1-1	190	B90
1-2	186	B90
1-3	186	B90
1-4	180	B88
1-5	184	B89
2-1	200	B92
2-2	193	B92
2-3	200	B92
2-4	196	B91
2-5	200	B92
3-1	200	B92
3-2	193	B91
3-3	190	B90
3-4	190	B90
3-5	196	B91

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TABLE III
ELEMENTAL COMPOSITION
(WEIGHT %)

<u>SAMPLE/AREA</u>	<u>SILICON</u>	<u>CHROMIUM</u>	<u>IRON</u>	<u>NICKEL</u>	<u>MOLYBDENUM</u>
1-1	0.31	18.54	REM	10.20	2.74
1-2	0.33	18.09	REM	10.21	3.22
1-3	0.32	18.71	REM	10.48	3.47
1-4	0.29	18.06	REM	10.63	3.35
1-5	0.26	18.79	REM	10.59	3.26
2-1	0.21	18.03	REM	11.59	3.21
2-2	0.32	18.21	REM	10.68	3.24
2-3	0.30	18.57	REM	10.53	2.67
2-4	0.31	18.80	REM	11.09	2.71
2-5	0.27	18.84	REM	10.97	3.54
3-1	0.29	17.81	REM	10.61	3.13
3-2	0.33	18.05	REM	10.72	3.28
3-3	0.20	18.42	REM	10.54	3.75
3-4	0.25	18.35	REM	10.62	3.65
3-5	0.23	18.41	REM	10.38	3.60

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M-1
#1
10X

REPORT NUMBER 06-15743

M-2
#1 - TOP
100X

REPORT NUMBER 06-15743

M-3
#1 - BOTTOM
100X

REPORT NUMBER 06-15743

M-4
#1 - CENTERLINE
100X

REPORT NUMBER 06-15743

M-5
#1 - HAZ
100X

REPORT NUMBER 06-15743

M-6
#2
10X

REPORT NUMBER 06-15743

M-7
#2 - TOP
100X

REPORT NUMBER 06-15743

M-8
#2 - CENTERLINE
100X

REPORT NUMBER 06-15743

M-9
#2 - HAZ
100X

REPORT NUMBER 06-15743

M-10
#3
10X

REPORT NUMBER 06-15743

M-11
#3 - TOP
100X

REPORT NUMBER 06-15743

M-12
#3 - BOTTOM
100X

REPORT NUMBER 06-15743

M-13
#3 - CENTERLINE
100X

REPORT NUMBER 06-15743

M-14
#3 - HAZ
100X

REPORT NUMBER 06-15743

M-15

REPORT NUMBER 06-15743

M-16

REPORT NUMBER 06-15743

M-17

REPORT NUMBER 06-15743

M-18

REPORT NUMBER 06-15743

M-19

REPORT NUMBER 06-15743

M-20

DIRATS

00006 16

BNL-91080-2007
TEST REPORT

William Powers
Acceleron, Inc.
21 Lordship Road
East Granby, CT 06026

Report Number 403633
Report Date 10-JUN-05
Page 1 of 1
Client Number 004800
Client Order 21839WP

RECEIVED 1 Section Welded Plate approx. 3/4" x 1 3/4"
IDENT AS Brookhaven Sample
MATERIAL 304 Stainless Steel
CONDITION *
TEST TO Client Instructions
TEST PER *
PURPOSE *
SPEC INST Return specimen and remnants

FAX 860-651-5881

PROPERTIES AS SUPPLIED

METALLOGRAPHIC EXAMINATION OF GROOVE WELD

Fusion: Good
Penetration: Complete
Voids: None
Pores: None
Cracks: None

Disp
For Info

WE CERTIFY THIS IS A TRUE COPY OF OUR RECORDS

Signed for J. Dirats and Co. by Eric E. Dirats, Audit Manager

NOTE: The recording of false, fictitious or fraudulent statements or entries on this document may be punished as a felony under federal law.

THOMAS W. EAGAR, Sc.D., P.E.
ROOM 4-136
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE, MA 02139-4307
617-253-3229
FAX 617-252-1773

June 11, 2004

Accelaron, Inc.
21 Lordship Road
East Granby, Connecticut 06026

Attention: Rory Montano

RE: Out of Vacuum Electron Beam Welds

Dear Mr. Montano,

On June 7, 2004 I inspected four welds plus photographs of additional welds made by your firm. The welds were made on 316 stainless steel, using 150 kV. Other parameters included:

1. High vacuum, 9 mA, 30 inches per minute.
2. High vacuum, 6 inches per minute.
3. Out of vacuum using plasma arc window, 6 inches per minute, made on March 25, 2004.
4. Similar to sample 3 but with reconfiguration of the plasma arc window, made April 28, 2004.

In my opinion, weld sample number 3 has the best appearance both on the top surface and in transverse cross-section. Welds 1 and 2 have the characteristic "nail head" shape of electron beam welds made in high vacuum, while weld 1 has the surface hump characteristic of very high speed welds. Weld 4 has part of this surface hump and a partial nail head cross-section. Weld 3 has an excellent top surface contour and a transverse shape similar to a very deeply penetrated gas tungsten arc weld. As such, weld 3 has the best surface uniformity and would be expected to have the best solidification structure.

Rory Montano
June 11, 2004
Page Two

Although my experience with evaluation of out of vacuum electron beam welds is nearly 30 years old, the bead shape represented by weld 3 is a significant improvement over the welds which were achievable in the past. I have also been informed that the bead shape is consistent at standoff distances of a few millimeters to 50 millimeters. If this is correct, this new plasma arc window represents a significant advance in out of vacuum electron beam welding technology.

Sincerely yours,

Thomas W. Eagar

Jh

[Click here to view a variety of photographs of the first welds performed utilizing the Plasma Arc Window.](#)

Note: We visited Thomas W. Eagar, Sc.D., P.E. at MIT on June 7, 2004. Tom is Head of the Materials Science and Engineering Department. We brought weld samples and photos for his evaluation and review. He was quite impressed with the weld and its geometry and has since sent us a letter with his comments. [Click here to view his comments and credentials \(PDF, 144k\).](#)