WORKSHOP ON

COMMERCIALIZATION OF PULSED POWER
SCIENCE AND TECHNOLOGY

PROCEEDINGS

August 18-20, 1993
San Francisco Airport Hilton
San Francisco, CA
WORKSHOP ON

COMMERCIALIZATION OF PULSED POWER SCIENCE AND TECHNOLOGY

PROCEEDINGS

August 18-20, 1993

San Francisco Airport Hilton
San Francisco, CA
Organizing Committee

Gabriel D. Roy, Chair
*Office of Naval Research*

Martin Gundersen
*University of Southern California*

Stephen Levy
*PEACE/EPRI*

Arthur Guenther
*Sandia National Laboratories*

Magne Kristiansen
*Texas Tech University*

Karl H. Schoenbach
*Old Dominion University*

*Group Leaders:*
- W. Hofer, *US Dept. of Energy* (Medical, Materials, Other)
- B. Penetrante, *LBL* (Environmental Applications)
- E. Chu, *Maxwell Labs.* (Power Electronics)

Sponsored by:

*Office of Naval Research*

*Local Arrangements:*
CK & Associates
Albany, California
TABLE OF CONTENTS

Foreword ............................................................................................................................. i

Workshop Attendees ............................................................................................................. ii

Workshop Agenda ................................................................................................................ iv

Repetitive Pulsed Power Technology and Commercial Applications
K. Prestwich, Sandia National Laboratories ................................................................. 1

Commercialization of Pulsed Power at Maxwell, Part II
Edmund Y. Chu, Maxwell Laboratories ............................................................................. 30

Pulsed Power for Civilian Applications
George Frazier, Physics International Co ........................................................................... 45

Overview of the Federal Technology Commercialization Program
N. Montanarelli, Technology & Applications Program, BMDO ............................. 62

Technology Transfer and Venture Capital
Barry M. Weinman, Newtek Ventures ................................................................................. 103

Working Group Reports
Medical, Materials, Other ................................................................................................. 118
Environmental Applications ............................................................................................... 124
Power Electronics .................................................................................................................. 142
Foreword

The new international environment has opened opportunities for pulsed power research that were not possible a few years ago. Pulsed power technology developed with Department of Defense support was primarily directed towards Department of Defense goals — perhaps more so than other areas of critical technology. There are, however, many significant applications for pulsed power in the commercial sector. The ability to tailor power pulse shapes and sequences and efficiently deliver energy in a pulsed, rather than DC or traditional AC mode, opens new horizons for commercial applications of lasers, accelerators, in medicine and pollution control, advanced motor control, and many other areas. There will be many applications for efficient, long-lived, reliable pulsed power that can be matched to applications requiring specialized voltage and current.

The 1993 Workshop on Commercialization of Pulsed Power Science and Technology brought together experts in the full range of problems facing technology transfer to discuss the issues facing commercialization and marketing. Those involved represented in addition to pulsed power expertise, experience in licensing, development, product engineering and marketing of new technology. The Workshop Proceedings provides a summary of discussion and expertise in all these areas.

We think the Workshop looks realistically towards the future. International development of products utilizing pulsed power is impressive, and the opening of this area for the commercial sector is, in our opinion, one with important consequences for the technological health of the nation. The areas cited above, and discussed in the Proceedings, such as power generation, efficient uses of power in industry and vehicles, and products for food processing and medical applications, will over the next decades impact jobs in market areas that are worth billions of dollars. It is extremely important that research, engineering, and product development be first rate, if we are to achieve substantial market-share in the future.

It seems clear that there is an important role for the organizations that have for so long supported the research that has produced the present level of expertise. As products develop, so do issues of a proprietary nature. Companies, after all, rise and fall depending on their ability to develop markets in very competitive environments. The support for research that will lead to new applications, in an open environment, must not be lost. Delicate proprietary issues must continually interface with the need for open research. The quality in engineering and the applied sciences, research results and an incredible level of quality in the skills of the scientists and engineers coming from government-supported university programs, largely the result of DoD support, is the envy of the world. We must maintain this — while continuing to foster commercial competitiveness — and we must address the needs of private companies that bring these results to the marketplace. Clearly, there will be many important and difficult problems for research management for years to come.

Martin Gundersen
Gabriel Roy
Karl Schoenbach
<table>
<thead>
<tr>
<th></th>
<th>Name</th>
<th>Address</th>
<th></th>
<th>Name</th>
<th>Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mr. John Allan</td>
<td>Power Spectra, Inc.</td>
<td>8</td>
<td>Dr. Mike Grothaus</td>
<td>Naval Surface Warfare Center</td>
</tr>
<tr>
<td></td>
<td></td>
<td>919 Hermosa Ct.</td>
<td></td>
<td></td>
<td>Pulsed Power Systems &amp; Technology</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sunnyvale, CA 94086</td>
<td></td>
<td></td>
<td>Code B20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>9</td>
<td></td>
<td>Dahlgren, VA 22448-5000</td>
</tr>
<tr>
<td>2</td>
<td>Dr. Edmund Y. Chu</td>
<td>Maxwell Laboratories</td>
<td>10</td>
<td>Prof. Martin Gundersen</td>
<td>Univ. of Southern California</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9244 Balboa Avenue</td>
<td></td>
<td></td>
<td>Dept. of Elec. Engr.-Electrophysics</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sunnyvale, CA 94086</td>
<td></td>
<td></td>
<td>Los Angeles, CA 90080-0484</td>
</tr>
<tr>
<td>3</td>
<td>Dr. Jeffrey Cukr</td>
<td>Defense Nuclear Agency/RAEV</td>
<td>11</td>
<td>Dr. Wayne Hofer</td>
<td>Dept. of Energy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6801 Telegraph Road</td>
<td></td>
<td></td>
<td>1000 Independence Ave.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Alexandria, VA 22310</td>
<td></td>
<td></td>
<td>Washington, DC 20585</td>
</tr>
<tr>
<td>4</td>
<td>Prof. William Donaldson</td>
<td>University of Rochester</td>
<td>12</td>
<td>Dr. Guenther A. Hofmann</td>
<td>BTX, Inc.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>250 East River Rd.</td>
<td></td>
<td></td>
<td>11199 A Sorrento Valley Rd.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rochester, NY 14623-1299</td>
<td></td>
<td></td>
<td>San Diego, CA 92121</td>
</tr>
<tr>
<td>5</td>
<td>Dr. George Frazier</td>
<td>Physics Intl. Co.</td>
<td></td>
<td>Mr. Myron Jones</td>
<td>EPRI</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2700 Merced St.</td>
<td>13</td>
<td></td>
<td>3412 Hillview Ave.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P.O. Box 5010</td>
<td></td>
<td>Dr. George Kirkman</td>
<td>P.O. Box 10412</td>
</tr>
<tr>
<td></td>
<td></td>
<td>San Leandro, CA 94577-0599</td>
<td></td>
<td></td>
<td>Palo Alto, CA 94303</td>
</tr>
<tr>
<td>6</td>
<td>Dr. David Goerz</td>
<td>Lawrence Livermore National Laboratory</td>
<td></td>
<td>Dr. Alex Kratel</td>
<td>Integrated Applied Physics</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P.O. Box 808 - L-153</td>
<td>14</td>
<td></td>
<td>50 Thayer Rd.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Livermore, CA 94550</td>
<td></td>
<td></td>
<td>Waltham, MA 02154</td>
</tr>
<tr>
<td>7</td>
<td>Prof. Julius Goldhar</td>
<td>University of Maryland</td>
<td></td>
<td></td>
<td>California Institute of Technology</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dept. of Electrical Engr.</td>
<td></td>
<td></td>
<td>MS 138-78</td>
</tr>
<tr>
<td></td>
<td></td>
<td>College Park, MD 20742</td>
<td></td>
<td></td>
<td>Pasadena, CA 91125</td>
</tr>
</tbody>
</table>
15 Prof. Magne Kristiansen
Texas Tech University
Dept. of Elec. Engr.-Pulsed Power Lab.
P.O. Box 4439
Lubbock, TX 79409-3102

16 Mr. Nick Montanarelli
BMDO (SDIO)
BMDO-DTI
Technology & Applications Program
Washington, DC 20301-7100

17 Dr. Tom Naff
Physics International
2700 Merced St.
Mail Stop 7000
San Leandro, CA 94577

18 Mr. Jeffrey Oicles
Power Spectra Inc.
919 Hermosa Ct.
Sunnyvale, CA 94086-4103

19 Dr. Bernie Penetrante
Lawrence Livermore National Lab.
P.O. Box 808
M.S. L427
Livermore, CA 94550

20 Mr. Kenneth Prestwich
Sandia National Laboratories
Div. 1240
P.O. Box 5800
Albuquerque, NM 87185-5800

21 Dr. Gabriel D. Roy
Office of Naval Research
Code 1132P
800 N. Quincy St.
Arlington, VA 22217-5000

22 Mr. John Sandelin
Stanford University
Technology Licensing Dept.
900 Welch Rd.
Stanford, CA 94305

23 Prof. Jim Sarjeant
SUNY Buffalo
312 Bonner ECE
SUNY/AB
Buffalo, NY 14260

24 Prof. Karl H. Schoenbach
Old Dominion University
Dept. of Elec. Engineering
Norfolk, VA 23529

25 Dr. George Schofield
Maxwell Laboratory
8888 Balboa Avenue.
San Diego, CA 92123

26 Mr. Howard Shaffer
Westinghouse Electric Corp.
1310 Beulah Rd.
501-3B28
Pittsburgh, PA 15235

27 Mr. Richard True
Litton Systems, Inc.
960 Industrial Rd.
San Carlos, CA 94070

28 Dr. Barry Weinman
Newtec Ventures
500 Washington St.
Suite 720
San Francisco, CA 94111

29 Mr. Leonard Whitlock
Ocean engineering Technologies, Inc.
2465 Portola Road
Ventura, CA 93003
WORKSHOP ON COMMERCIALIZATION OF PULSED POWER SCIENCE AND TECHNOLOGY

SAN FRANCISCO AIRPORT HILTON
SAN FRANCISCO, CA
AUGUST 18-20, 1993

AGENDA

WEDNESDAY, AUGUST 18

8:00 - 8:30 a.m.  Registration

8:30 - 8:45 a.m.  "Introduction and Objectives"
                 G. Roy, Office of Naval Research

8:45 - 9:15 a.m.  "Repetitive Pulsed Power Technology and Commercial Applications"
                 K. Prestwich, Sandia National Laboratories

9:15 - 9:45 a.m.  "Commercialization of Pulsed Power Technology at Maxwell, Part II"
                 E. Chu, Maxwell Laboratories

9:45 - 10:15 a.m. Coffee Break

10:15 - 10:45 a.m. "Overview of the Federal Technology Commercialization Program"
                   N. Montanarelli, Technology and Applications Program, BMDO

10:45 - 11:15 a.m. "Technology Transfer and Venture Capital"
                    B. Weinman, Newtec Ventures

11:15 - 11:45 a.m. Discussion, Formation of Working Groups

12:00 - 1:30 p.m.  Lunch

1:30 - 5:00 p.m.  Working Group Meetings
                   a) Power Electronics
                   b) Environment
                   c) Materials Treatment
                   d) Medical Applications
                   e) Other Applications
Pulsed power researchers will have the opportunity to present their ongoing or planned work (with respect to its commercialization). Potential users of pulsed power technology will present their views on the applicability of pulse power technology for their particular applications. The discussion will focus on the assessment of the technical and commercial potential of proposed technologies and on new applications for existing technologies.

6:30 p.m.  Reception
7:30 p.m.  Dinner/Speaker
"Technology Transfer through Licensing"
J. Sandelin, Stanford University

THURSDAY, AUGUST 19
8:00 - 10:00 a.m.  Group Report Preparation
10:00 - 10:30 a.m.  Coffee Break
10:30 - 12:30 p.m.  Group Reports and Discussion
12:30 - 2:00 p.m.  Lunch
2:00 - 3:30 p.m.  Panel Discussion
Topics:
- Potential of Discussed Pulsed Power Technologies
- New Applications/Markets
- Networking
- Technology Transfer Paths
- Patents, Licensing
Participants:
- Pulsed Power Researchers (National Labs, Companies, Universities), Users, Government Representatives, Investors

3:30 - 4:00 p.m.  Coffee Break
4:00 - 5:00 p.m.  Discussion, Recommendations

FRIDAY, AUGUST 20
8:30 - 12:00 p.m.  Workshop Organizing Committee Meeting
Draft meeting report
12:00 p.m.  Adjournment
REPETITIVE PULSED POWER TECHNOLOGY
AND COMMERCIAL APPLICATIONS

K. Prestwich
Sandia National Laboratories
105 CRADAs for value of $378,000,000

Energy & Env.
10 CRADAs

Computing
14 CRADAs

Manufacturing
14 CRADAs

Materials
21 CRADAs

Microelectronics
58 CRADAs

100+
Some Sandia Technologies with Major Commercial Applications

Polycrystalline Diamond Drill Bits

Whitfield Laminar Flow Clean Room

Liquid Solder Leveler for Printed Circuit Boards

Rolamite Inertial Switch for Automobile Airbags
Pulsed Power Sciences Provides Solutions to Problems of National Importance

W68/Mk3
Nuclear Hardness and Survivability Testing

Power Compression
- Energy Storage
- Power
- Time - sec
- Watts
- Pulse Forming
- Beams

Beam & Target Physics
- Cathode
- Anode
- Target
- Focused Ion Beam

Fusion Research

Defense Applications
- Incident High Power Microwaves

Industrial Applications
- Ion Beam Processing
- Surface Treatment
Pulsed Power Sciences Has a Broad Spectrum of Capabilities

- Beam and plasma physics
- Simulation and modeling
- Component, code, and diagnostics development
- Systems Engineering
- Testing

Hermes III 20 MeV Radiation Simulator

PBFA II ICF Driver

Split Cavity Oscillator Microwave Source

Complex Simulations

RHEPP 1 MeV 250 kW Beam Source
WESTINGHOUSE DESIGNED 15 KV TO 270 KV PULSE TRANSFORMER IS ASSEMBLED

Sandia National Laboratories

OUTPUT LEAD

4 PARALLEL WIRE SECONDARY WINDINGS

INPUT LEADS

4 PARALLEL COPPER SHEET PRIMARY WINDINGS

FILE: C:\1243VIEW\XFMR01C.DRW
POSSIBLE APPLICATIONS REQUIRE ACCELERATORS WITH HIGH AVERAGE POWER CAPABILITIES

Average Beam Power

1GW
100MW
10MW
1MW
100KW
10KW

Applications

Transmutation of Nuclear Waste
Inertial Confinement Fusion
Flue Gas Cleanup
Cellulose Degradation
MATERIALS PROCESSING
Medical Waste Treatment
Radiation Processing of Polymers
Food Processing
Sludge Treatment

Sandia National Laboratories
High Average Power Short-Pulse Accelerators Share Concepts

- Semiconductor Switches
- Thyatron Switches
- Alternator Magnetic Switches
- Magnetic Pulse Compressor
- Linear Induction Adder
- Dispenser Cathode
- Cold Field Emitting Cathode

10's of ns

1 - 20 MeV

ms to usec
The Physics International CLIA Accelerator Uses Thyristrons and Magnetic Switches

Pout = 120 kW

Beam voltage = 750 keV
Beam current = 10 kA
Pulse width = 100 nS
PRF, up to 250 Hz

Courtesy of S. Ashby
The Magnetic Pulse Compressor can drive a Pulse Forming Network with high voltage cable output
RHEPP SYSTEM WILL GENERATE 400 KW BEAMS

2.5 MV, 10 STAGE INDUCTION ADDER

60 NS PULSE COMPRESSOR

1 µSEC PULSE COMPRESSOR

DIODE & CONVERTER BELOW SHIELD BLOCKS
FIRST STAGE SWITCH USES SILICON IRON CORES AND OIL COOLED WIRE WINDINGS

- RESET WINDINGS
- WIRE WINDINGS
- OIL COOLING PORTS
- SILICON-IRON CORES
FIRST 250 KV MAGNETIC SWITCH IS OPERATIONAL AT 600 KW POWER LEVEL
Polish pilot plant for e-beam processing of flue gas is operational

Power Plant
NO-200 ppm
SO₂-800 ppm

Spray Cooler
70 - 90°C

Ammonia Injection

Reaction Vessel
2-3 chambers

Bag Filter

Ammonium Sulphate and Nitrate

E-beam Power Source
(700 keV, 2 - 50 kW)

after:
Chmielewski, Iler, Zimek, and Licki
please see proceedings of:
8th International Meeting on Radiation Processing

also:
a 1.5 MW facility is being built by
Science Applications International Corp

F:UEPLNT.DRW

ELN 5/31/93
Pulsed plasma reactors can destroy NO\textsubscript{X}, additives improve process

Pulsed reactor:
Vp = 50 kV,
FWHM < 200 ns

\textbf{NO}_X\textsubscript{X} destruction vs time with n-Octane additive

from: G. E. Vogtlin, LLNL
THE PFL PROVIDES PULSE SHAPING & TWO STAGES OF MAGNETIC PULSE COMPRESSION

TRI-AXIAL PFL

OUTPUT SWITCH

INVERSION SWITCH

CHARGING CORE

EFFICIENCY = 90%
1 MV, 4 STAGE, LINEAR INDUCTION ADDER IS ASSEMBLED ON SHIELDING PIT

20 CABLE PORTS
REPETITIVE INDUCTION ADDERS USING AN MITL OR VACUUM INSULATION NEEDED FOR HV ACCELERATORS

Vacuum Insulator
Magnetic Core
Input

-To Diode

A) Examples - Helia, Hermes III, RHEPP
B) Parameters (Single Shot Demonstrated)
Voltage: 4 to 20 MeV
Current: 10 to 700 KA
THE RHEPP PROGRAM IS DEVELOPING HIGH AVERAGE POWER E-BEAM ACCELERATORS

May 1992

V = 250 KV
PRF = 0-500 Hz
Ipk = 2500 A
Tp = 70 ns FWHM
Eout = 50 J
Pout = 22 KW

December 1992

V = 0.9 MV
PRF = 120 Hz
Ipk = 25 KA
Tp = 60 ns FWHM
Eout = 1250 J
Pout = 160 KW

September 1993

V = 2.25 MV, PRF = 0-120 Hz
Ipk = 25 KA, Tp = 60 ns FWHM
Eout = 3000 J
Pout = 400 KW

10 ft
The MAP ion beam system on RHEPP is compact, easy to maintain.

The Cornell Magnetically-confined Anode Plasma ion beam system is designed for repetitive operation on RHEPP at 1 MeV and 50 kA.

This initial version is designed for operation in burst mode only.
IBEST Uses Pulsed Ion Beams to Melt and Modify Surfaces

Ion Beam Surface Treatment

- $^1H^+$ beam at 0.5 - 1 MeV
- Ion range of 3 - 7 micrometers
- 2 - 8 J/cm$^2$ for melt
- Rapid cooling ($10^{10}^\circ K/s$) due to thermal diffusion into substrate
IBEST Modifies Material Surfaces and Increases Hardness

Before

After 4 pulses

5 μm O-1 tool steel

- treated: hardness = 9.05 GPa
- untreated: hardness = 3.39 GPa

Tool steel surface hardening

Titanium machined surface
Many scientific studies and conferences have shown the advantages of irradiation for food safety.

Safeguarding the Food Supply through Irradiation Processing Techniques

An International Conference on Facilitating the Commercial Adaptation of Food Irradiation Technology

October 25-31, 1992
Sheraton World Resort
Orlando, Florida USA

Presented by The Agricultural Research Institute
1450 Rockville Pike
Bethesda, MD 20814 USA

- Ionizing radiation treatment
- Increases food safety by effectively controlling pathogenic bacteria growth:
  - Salmonella
  - Trichinae
  - E. coli
  - Vibrio Vulnificus
- No residual radioactivity
- Effective for insect disinfestation
- Can reduce spoilage and extend shelf-life
- No harmful chemical changes
- Insignificant adverse effect to nutritional value
LOW DOSES OF RADIATION CAN BE USEFUL IN CONTROLLING FOOD BORNE DISEASES

IN THE UNITED STATES, FOOD BORNE DISEASES:
- CLAIM 7000 LIVES PER YEAR
- CAUSE 24-81 MILLION CASES OF DIARRHEAL DISEASES
  AT A COST OF $5B - $17B (FDA)
  (CENTER FOR DISEASE CONTROL)

DOSES OF 0.1 TO 1 MRAD CONTROL THE PATHOGENIC BACTERIA
- (CODEX ALIMENTARIUS COMMISSION)

APPROVED IN 37 COUNTRIES
- 40 FOOD PRODUCTS
- 24 COUNTRIES HAVE COMMERCIAL OPERATIONS
  (ELECTRONS ARE USED TO IRRADIATE DEBONED CHICKEN IN FRANCE)

[ SOURCE - INTERNATIONAL CONSULTATIVE GROUP ON FOOD IRRADIATION ]
HIGH AVERAGE POWER X-RAY GENERATORS ARE REQUIRED FOR VOLUME FOOD PROCESSING

Throughput - Kg/hr

10^6

10^5

10^4

10^3

10^2

10 Krad

100 Krad

1 Mrad

10 Mrad

1 MW POWER

10 KW POWER

Grains

Insect Disinfestation

Plant Quarantine

Fruits Vegetables

Extend Shelf Life

Meats Poultry Shellfish

Reduce Spoilage and Bacteria

Spices Seasoning

Sandia National Laboratories

C:\12AS\VIEW\FOOD.DRW

ELH 1/3/93
IRRADIATION WITH E-BEAMS CAN EFFECTIVELY DESTROY VARIOUS ORGANIC CONTAMINANTS

Sandia National Laboratories

Graph showing the relationship between throughput (gallons per hour) and dose (krads and mrads) for different power levels (1 MW and 10 kW) for potable water supplies, groundwater, and mixed waste.
BEAM STERILIZATION OF BIOLOGICAL HAZARDS BECOMES FEASIBLE AT REALISTIC FLOW RATES

Sandia National Laboratories

THROUGHPUT - KG/HR

10^8
10^7
10^6
10^5
10^4
10^3
10^2

10 Krad
1 Mrad
100 Mrad

DOSE

HOUSTON
SEWAGE TREATMENT
ALBUQUERQUE

SANTA FE

REGIONAL FACILITY
MEDICAL WASTE STERILIZATION

MEDICAL DEVICES

COSMETICS

DRUGS

SINGLE FACILITY

FOR X-RAYS
EFF = 2%
REQ'D POWER
0.5 TO 40 MW

1 MW
10 KW

KILL VIRUS MICRO-ORGANISMS
The near term availability of short-pulse high average power accelerators is opening the door for new environmental and industrial applications.
Repetitive Pulsed Power Technology Will Support Important Industries

Applications

- Materials Processing
- Synthesis
- Food Sterilization
- Pulsed Power Sciences
- Quantum Manufacturing
- Pollution Control
- Hazardous Organic Waste Destruction

Atmospheric Electron Beam Welding
COMMERCIALIZATION OF PULSED POWER AT MAXWELL, PART II

PRESENTED BY
EDMOND Y. CHU
PRESENTATION OVERVIEW

- BRIEF DESCRIPTION OF MAXWELL
- QUESTIONS WE HAD PRIOR TO COMMERCIALIZATION
- THINGS WE LEARNED TO DATE
- CHALLENGES AHEAD OF US
BRIEF HISTORY OF MAXWELL

- FOUNDED IN 1966 TO DEVELOP AND MANUFACTURE HIGH ENERGY DISCHARGE CAPACITORS
- DEVELOPMENT OF PULSED POWER TECHNOLOGY HAS BEEN DRIVEN BY DNA'S NEED TO DEVELOP NUCLEAR WEAPON EFFECTS SIMULATOR
- WE HAVE ALSO BEEN BUILDING VARIOUS CUSTOM DESIGNED PULSED POWER SYSTEMS FOR CUSTOMERS SUCH AS: GOVERNMENT AGENCIES, NATIONAL LABORATORIES, AEROSPACE COMPANIES.
THE YEARS OF GROWTH

- 1984, MAXWELL MADE ITS FIRST ACQUISITION -- S-CUBED, A COMPANY THAT DERIVED MOST OF ITS REVENUE FROM GOVERNMENT
- IN THE SUBSEQUENT YEARS, WE ACQUIRED:
  - BROBECK, AN ACCELERATOR TECHNOLOGY COMPANY
  - PART OF IRT
  - I-BUS, A PC-BASED CONTROL ELECTRONICS COMPANY
  - SIERRA, A HIGH RELIABILITY, LOW VOLTAGE CAPACITOR COMPANY
- HAVE ALSO SPUN OFF THE FOLLOWING BUSINESS UNITS:
  - BUSINESS SYSTEMS: BUSINESS ACCOUNTING SOFTWARE
  - FOOD CO: FOOD PACKAGE STERILIZATION
- ORIGINAL MAXWELL HAS BECOME THE BALBOA DIVISION, WHICH STILL DERIVES MOST OF ITS REVENUE FROM GOVERNMENT (DIRECTLY OR INDIRECTLY)
STRATEGIC GOAL FOR THE BALBOA DIVISION

ACCELERATE COMMERCIAL BUSINESS GROWTH IN ORDER TO ACHIEVE A MORE BALANCED GOVERNMENT AND COMMERCIAL BUSINESS BASE
QUESTIONS WE HAD A FEW YEARS AGO REGARDING COMMERCIALIZATION

- HOW?
  - BY DEVELOPING NEW PRODUCTS?
  - THROUGH ACQUISITION?
- WHAT BUSINESS/PRODUCT?
- DO WE HAVE THE RIGHT PEOPLE?
- DO WE HAVE THE RIGHT CULTURE?
- DO WE HAVE THE RESOURCES?
- DO WE KNOW HOW TO SELL TO COMMERCIAL MARKET?
- WILL WE BE COMPETITIVE?
- ......
WHAT WE LEARNED ABOUT TECHNOLOGY?

- RELIABILITY
- LONG LIFE
- CUSTOMER FOCUSED
WHAT WE LEARNED ABOUT MANUFACTURING?

- HIGHEST QUALITY
- LOWEST COST
- RESPONSIVENESS
MARKETING/SELLING

- BE CLOSE TO THE CUSTOMER
- LISTEN WELL
THE THREE-RING CIRCUS MODEL FOR PRODUCT/BUSINESS DEVELOPMENT GIVEN LIMITED RESOURCES

- THREE SETS OF CLOSELY COORDINATED ACTIVITIES:
  - TECHNOLOGY/ENGINEERING
  - MANUFACTURING
  - MARKETING/SELLING
- DIFFERENT STAGES OF THE DEVELOPMENT REQUIRE MORE EMPHASIS ON PARTICULAR SET OF ACTIVITIES
- BY FOCUSING RESOURCES ON ONE SET OF ACTIVITIES AT A TIME, DESIRABLE GROWTH CAN BE ACCOMPLISHED IN SPITE OF LIMITED RESOURCES
PROPER ENVIRONMENT & CULTURE IS ESSENTIAL FOR GROWTH

- DEVELOP AND FOLLOW THE VISION
- UNDERSTAND THE GOAL
- TEAM WORK
- OWNERSHIP AND EMPOWERMENT
- PERSONNEL DEVELOPMENT
- COMMUNICATIONS
- PROBLEM SOLVING SKILLS
- PRIORITY MANAGEMENT
- MEASURING AND REWARDING GREAT PERFORMANCE
UNDERSTANDING THE NUMBERS

- ACTIVITY BASED COST ACCOUNTING
  - PROFIT = REVENUE - EXPENDITURE
- INCREASING SHAREHOLDER VALUE IS KEY
- INVESTMENT RISKS
STRATEGIC ALLIANCE CAN OFFER LEVERAGE

- TRUST, COMMITMENTS, AND COMMUNICATIONS ARE KEY
- THE RELATIONSHIP MUST BUILD ON CORE STRENGTHS
  OF TEAM MEMBERS
- A LOT OF WORK AND WILLINGNESS TO COMPROMISE TO
  MAKE IT WORK
- "THERE IS NO FREE LUNCH"
WHAT CHALLENGES AHEAD FOR US?

- CONTINUE TO EXPAND EXISTING PRODUCTS AND DEVELOP NEW PRODUCTS TO ASSURE ORGANIZATION STAYS "YOUNG"
- MANAGING CONFLICTS BETWEEN DIFFERENT TYPES OF BUSINESSES
- IMPROVE THE SPEED OF CHANGE
- BALANCE BETWEEN SHORT TERM AND LONG TERM PROFITABILITY
CONCLUSION

- It is possible for a company that has been doing predominantly government business to commercialize pulsed power technology.
- Leadership, cultural change, and training are crucial in succeeding the transition.
- Must be strong in technology, manufacturing, and selling in order to survive and excel in the new world. Being good at only one of these areas is not adequate any more.
PULSED POWER FOR CIVILIAN APPLICATIONS

By

George Frazier
Physics International Company
San Leandro, California

(Originally presented at the Joint Workshop: Power Semiconductor Coordination Committee (PSCC) and Inter-Agency Power Group (IAPG) February 8 - 11, 1993 EPRI Conference Center Palo Alto, California)
Pulsed Power for Civilian Applications—Outline

- Basic message
- Pulsed power background
- Converting defense-related pulsed power technology into civilian use or dual use
- Vision for the future and summary
Basic Message

- The Departments of Defense (DoD) and Energy (DoE) have been investing in defense-related pulsed power technology for over 50 years. There is a tremendous body of knowledge and expertise available.

<table>
<thead>
<tr>
<th>Defense Agencies</th>
<th>Service Labs</th>
<th>National Labs</th>
<th>Universities</th>
<th>Contractors</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNA</td>
<td>ARL</td>
<td>SNLA</td>
<td>South Carolina</td>
<td>PI</td>
</tr>
<tr>
<td>DARPA</td>
<td>NRL</td>
<td>LLNL</td>
<td>Tennessee</td>
<td>MLI</td>
</tr>
<tr>
<td>SDIO (NASA)</td>
<td>NSWC</td>
<td>LBL</td>
<td>Texas Tech</td>
<td>Titan</td>
</tr>
<tr>
<td></td>
<td>Phillips</td>
<td>LANL</td>
<td>UT-Austin and</td>
<td>SRL</td>
</tr>
<tr>
<td></td>
<td>AFWAL</td>
<td>INEL</td>
<td>Arlington</td>
<td>SAIC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SUNY Buffalo</td>
<td>W</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Auburn</td>
<td>ITT</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Old Dominion</td>
<td></td>
</tr>
</tbody>
</table>

- The world has changed. Defense cutbacks are affecting pulsed power companies and jobs. Overcapacity looms.

- Potential civilian applications are numerous but undeveloped. Defense conversion is key to preserving pulsed power capabilities. Organizations like EPRI, PSCC, and IAPG are vital to success.
Pulsed Power Background

- Definition and Advantages
- Defense-related Applications
- Examples of Defense Technology Base

What is Pulsed Power?

The technology of producing precisely shaped electrical pulses. Peak-to-average power ratios are high.

Typical Parameter Ranges (Current SOA)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Power:</td>
<td>100 MW to 100 TW</td>
<td>(10^8-10^{14}) watts</td>
</tr>
<tr>
<td>Average Power:</td>
<td>10 W to 10 MW</td>
<td>(10^1-10^7) watts</td>
</tr>
<tr>
<td>Peak Voltage:</td>
<td>10 kV to 10 MV</td>
<td>(10^4-10^7) volts</td>
</tr>
<tr>
<td>Peak Current:</td>
<td>1 kA to 10 MA</td>
<td>(10^3-10^7) amps</td>
</tr>
<tr>
<td>Energy per Pulse:</td>
<td>1 J to 60 MJ</td>
<td>(10^0-6 \times 10^7) joules</td>
</tr>
</tbody>
</table>

Three to seven orders of magnitude in each parameter.
Unique Advantages of Pulsed Power

Precise Electrical Energy Delivery:
• Can exploit rate-dependent effects
• Can optimize system responses

High Peak-to-average Power Ratio
• Can exploit threshold effects
• Can excite non-linear effects
• Can minimize unwanted heating (more efficient than dc)

Short Pulse Timing Advantages
• Can deliver energy, then wait (e.g., for chemical reactions)
• Can exploit time domain (e.g., radar)
• Can avoid competing processes (e.g., breakdown)

Environmentally Friendly
• May replace toxic chemicals for some applications
• Little or no residual radioactivity
Basic Elements of a Pulsed Power or Power Modulator System

Prime Power
- Starting point
- Usually a mechanical device: Gas Turbine, Engine, Hydro-turbine
- Usually gives shaft horsepower out

Power Generation
- Produces electrical power
- Usually an electromechanical device: Alternator, Generator
- Usually uses shaft horsepower
- Usually provides ac electricity out

Power Conditioning
- Converts electricity to a more usable form
- Types of Conversion: -ac to ac, -ac to dc, -dc to ac, -dc to dc
- Matches voltage requirements of modulator to output of generator

Pulse Modulation
- Produces a train of electrical pulses
- Makes pulse characteristics match load requirements

End Use Device (Load)
- Uses modulated pulses to produce:
  - Particle beams
  - Electromagnetic radiation
  - Direct electrical pulses

Commercial power grid unless system is transportable
A Simplified Pulse Modulator Circuit Showing Energy Storage, Switching, Compression and Transformation
There are Three General Categories of Intense Pulses Produced by Pulsed Power Systems

- Pulse Modulator
  - Particle Accelerator
  - Radiation Source
  - Antenna
  - Laser

  Electromagnetic Radiation

- Particle Accelerator

- Direct Electrical Pulse Load
  - Fields, Plasmas, etc.

  Direct Electrical Pulse Effects
Direct Electrical Pulses Can Support a Wide Range of Physics and Chemistry

<table>
<thead>
<tr>
<th>Direct Electrical Pulse Load</th>
<th>Fields, Plasmas, etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specially configured electrodes: plates, wires, coaxes, etc.</td>
<td>Electric Fields</td>
</tr>
<tr>
<td>Specially configured conductors: magnets, transmission lines, etc.</td>
<td>Magnetic Fields</td>
</tr>
<tr>
<td>Electrodes connecting to load: EM guns, current injectors, etc.</td>
<td>High Currents</td>
</tr>
<tr>
<td>Hot-dense Z-pinches, imploding plasmas, electric arc discharges</td>
<td>Thermal Plasmas</td>
</tr>
<tr>
<td>Pulsed corona discharges</td>
<td>Non-thermal Plasmas</td>
</tr>
<tr>
<td>Pulsed magnets or electrical discharges</td>
<td>Acoustic Shocks</td>
</tr>
</tbody>
</table>
A Wide Variety of Pulsed Power Devices Produce Beams and Radiation

- Pulsed rf and induction accelerators or channel sparks
- Accelerator driving radiation converters
- Lasers
- Flashlamps
- Relativistic microwave sources: magnetrons, klystrons, BWOs, etc.
- Conventional microwave tubes: magnetrons, klystrons, TWTs, etc.
- Radiating antennae and transmission lines

Particle Beams
- Electrons
- Ions
- Neutrals

Electromagnetic Radiation
- X-rays/γ-rays
- Coherent light (IR to UV)
- Incoherent light
- High Power Microwaves/RF
- Conventional Microwaves/RF
- Impulses/EMP
# Defense-Related Pulsed Power Applications

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle Beams:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Electrons</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Ions</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Neutrons</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electromagnetic Radiation:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- X-rays/γ-rays</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>- Coherent Light (IR-UV)</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Incoherent Light</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- High Power Microwaves/RF</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Conventional Microwaves/RF</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Impulses/EMP</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct Electrical Pulses:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Electric Fields</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>- Magnetic Fields</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>- High Current</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>- Thermal Plasmas</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>- Non-thermal Plasmas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Acoustic Shocks</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Pulsed Power Defense Conversion: Contrasts Between Military and Civilian Programs

DoD/DoE Pulsed Power Conversion

- Performance is paramount
- Cost is secondary (at most)
- Technology is usually cutting edge
- "ilities" relate to battlefield:
  1. Lethality
  2. Survivability
  3. Vulnerability
  4. Transportability
  5. Reliability
  6. Maintainability
  7. Affordability
  8. Lifetime

- "ilities" are largely undeveloped. Except for radar, there is no weaponized pulsed power system. Most systems support R&D.

Commercial Pulsed Power

- Only sufficient performance is needed
- Cost is paramount
- Proven technology is needed
- "ilities" relate to cost:
  1. Affordability
  2. Lifetime
  3. Maintainability
  4. Reliability

- There is little large scale commercial use of pulsed power yet, but some examples exist (e.g., defibrillators), others are emerging.
Existing Defense - Related Pulsed Power Parameter Space

```
Average, Power

10 MHz  10 kHz  1 kHz  100 Hz  10 Hz

0.1 Hz  1 Hz

10^{-2} Hz  10^{-3} Hz  10^{-4} Hz  10^{-5} Hz

Energy/Pulse

0.1 J  1 J  10 J  100 J  1 kJ  10 kJ  100 kJ  1 MJ  10 MJ  100 MJ

 Likely Burst Limit
 Practical CW Limit

• LLNL LIS (CW)
• CLIA (CW)
• SLAC (CW)
• RHEPP (CW Design)
• ETA II (Burst)
• ETD Van (Burst)
• ATA (CW)
• ARDEC PPM (Burst)
• AURORA (SS)
• DECADE (SS)
• PBFA II (SS)
```
Many Potential Commercial Applications for Modulator and Pulsed Power Technology Have Been Identified*

The EPRI Power Electronics Applications Center (PEAC) identified 66 applications in a study last year. More are being added in all six categories:

1. Industrial
2. Medical
3. Agricultural
4. Environmental
5. Transportation
6. Chemical

A cursory study of a few selected applications reveals significant overlap in technical requirements.

Approximate Requirements for Selected Commercial Applications
Some Issues for Military-to-Civilian Use Transition

Must engineer systems for long life, high reliability and low life-cycle cost

<table>
<thead>
<tr>
<th>Military</th>
<th>Civilian Use</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. System concepts are well developed. Many components have a reliability database.</td>
<td>Many systems and components can be adapted with little or no development</td>
<td>- Control systems and sensors - Power supplies - Magnets - High voltage insulation</td>
</tr>
<tr>
<td>2. Some critical components have been demonstrated at high energy, high power</td>
<td>Long life, practical thermal management, maintainability are more important:</td>
<td>Need to select high margin, derated designs:</td>
</tr>
<tr>
<td>- But often work to design margins and have limited life (ok for R&amp;D)</td>
<td>- 1 year (10^7-10^9) shots (10) maintenance cycle - 10-20 years lifetime</td>
<td>- SCRs demonstrated &gt;800,000 hr life and &gt;9,000 hr MTBF (LLNL LIS Cu Laser System) - Low energy density capacitors should demonstrate better life dependence on voltage, i.e. better than (V^{-7}) - Pulse transformers need cooling and derating for continuous use</td>
</tr>
<tr>
<td>3. Machines directed at trained and sophisticated users</td>
<td>- Easy operation and troubleshooting essential - Operate unattended, limited access for rapid repair</td>
<td>- Need built-in self diagnostics - Fool proof, automatic protection and shutdown</td>
</tr>
</tbody>
</table>
Summary and Comments on the Future

- Defense-related pulsed power has great potential for commercial use.

- There is a military-civilian gap that must be bridged:

  **Military R&D**
  - High-risk, high payoff
  - Government funds and assumes most risk
  - Performance paramount
  - Custom designs, mainly R&D related

  **Civilian Applications**
  - Low-risk, reliable
  - Private industry assumes risk
  - Economics paramount
  - Standard designs, mainly production related

- Bridging the gap can be accomplished through joint ventures, CRADAs, and partnerships.

- Funds for the process must come from the government (defense conversion and transition programs) and private investment.

- This process has started (e.g., SERDP, EPRI work, etc.) but needs further support.
OVERVIEW OF THE FEDERAL TECHNOLOGY COMMERCIALIZATION PROGRAM

N. Montanarelli
Technology and Applications Program
BMDO
BALLISTIC MISSILE DEFENSE ORGANIZATION

Technology Applications Program
FY 93 NATIONAL DEFENSE AUTHORIZATION ACT

Technology Reinvestment Project (TRP)

- Dual Use Critical Technology Partnerships
- Commercial Military Integration Partnerships
- Regional Technology Alliances Assistance Program
- Defense Advanced Manufacturing Technology Partnerships
- Manufacturing Extension Programs
- Defense Dual Use Assistance Extension Program

Total FY 93 Funding - $475M
OFFICE OF TECHNOLOGY TRANSITION (OTT)

- Authorized By The National Defense Authorization Act Of FY 93

- Established April 1993, Within OSD / DDR&E

- Status
  - Report To Congress "Encouragement Of Technology Transfer"

  - Defense Technology Transfer Working Group (OSD, Services, BMDO, DNA And ARPA)
    - Identify DoD $T^2$ Activities And Accomplishments
    - Assess DoD Labs Core Competency In Dual Use Technologies
    - Investigate Existing Barriers To $T^2$
    - Provide Recommendations To Streamline The $T^2$ Process
DoD TECHNOLOGY TRANSFER

Post Cold War Environment

Past

- Stevenson-Wydler / Technology Transfer Acts
  - Laboratory Offices Of Research And Technology Application (ORTA)
  - Cooperative Research And Development Agreements (CRADAs)
  - Small Business Innovative Research (SBIR) Reauthorization

Influencing Factors

- Defense Budget Reductions

- DoD Laboratory Consolidation

Status

- Strength: Defense T² Successes
  - Robust SBIR Program
  - Defense Technology Commercialization
  - CRADA Quantity And Quality

- Weakness: OSD Lacks Strong T² Policy
  - No Funding For T² Activities
  - Services' Non-standard T² Implementing Procedures
  - No Measurement Standards For T² Success
PRESIDENT CLINTON'S TECHNOLOGY INVESTMENT PLAN

"Technology For America's Economic Growth
A New Direction To Build Economic Strength"

- A National Industrial Policy
  - Boost America's Global Economic Competitiveness

- Approach
  - Accelerate Development / Application Of commercially Viable Technologies

- Technology Goals
  - Create Jobs And Protect The Environment
  - Make Government More Efficient And Responsive
  - Obtain World Class Leadership In Science, Math, And Engineering
  - Start New Initiatives To Build Economic Strengths
FEATURES OF THE TECHNOLOGY PLAN

• Emphasis On
  - Dual Use Technology Commercial Applications
  - Cost-shared Government - Industrial Partnerships
  - New Technology Demonstration (Pilot) Programs
  - National "Information Superhighway" Network
  - Access To Existing And Emerging Technology "Know-how"
  - Research And Development / Manufacturing Extension Centers
  - Flexible Manufacturing Processes
  - Enhanced Basic Science Research
  - Permanent Research And Experimental Tax Credit
<table>
<thead>
<tr>
<th>ITEM</th>
<th>TIME GAP</th>
<th>COMMERCIALIZATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluorescent Light</td>
<td>82 years</td>
<td>1934</td>
</tr>
<tr>
<td>Ball Point Pen</td>
<td>50 years</td>
<td>1938</td>
</tr>
<tr>
<td>Helicopter</td>
<td>32 years</td>
<td>1936</td>
</tr>
<tr>
<td>TV</td>
<td>29 years</td>
<td>1936</td>
</tr>
<tr>
<td>Transistor</td>
<td>10 years</td>
<td>1950</td>
</tr>
<tr>
<td>Zipper</td>
<td>32 years</td>
<td>1923</td>
</tr>
<tr>
<td>Radar</td>
<td>46 years</td>
<td>1933</td>
</tr>
<tr>
<td>Diesel Locomotive</td>
<td>39 years</td>
<td>1934</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BUZZ WORDS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Strategic Partnerships</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Dual Use Technology</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Defense Conversion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Industrial Consortia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Regional Alliances</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Manufacturing Technology</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Technology Transfer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Technology Applications</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Technology Utilization</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Spin-offs</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

...
NOTE: Excludes DOE and Theater Missile Defense (TMD) Funding
SDI TECHNOLOGY APPLICATIONS

SPACE STRUCTURE

ERIS

SPACE LASER

SPACE SENSOR

SPACE MIRROR & OPTICS

INTERCEPTOR

SPACE EXPERIMENTS

SPACE LASER

SPACE MIRROR & SENSOR

- Carboid Fiber Ceramic Materials
- Light Weight Prosthetics Artificial Joints
- Earth's Atmospheric Data Sharing
- Eye Surgery
- Aberration Interferometric Differencing Analysts (AIDA)
- Optical Coatings Machine Tools
- Diamond Crystal Coating Technology
- High Temperature Carbon Fiber Materials
- Integrated Background Signature Survey (IBSS)
- Contraband and Explosives Detection
- Oil Well Drilling
-mini Sensor Package Transmission of Pulsed Power
- Surveillance and Detection
- Microsurgical Instruments
- Manufacturing Technologies
- Automotive and Engine Components
EVOLVING BALLISTIC MISSILE CAPABILITY

- Netherlands
- Germany
- Poland
- Czechoslovakia
- Hungary
- Romania
- China
- North Korea
- South Korea
- Taiwan
- Vietnam
- India
- Afghanistan
- Brazil
- Libya
- France
- Italy
- UK
- Argentina

 Missile Models:
- Scud
- FROG-7
- Badr
- Condor 2
- SS-21
- Al Anbed
- Al Abbas
- Al Hussein
- Alacran
- Condor 2
- MB / EE
- SS-300 / 1000
- Amistan
- Iran 130
- Hatf 1
- Hatf 2
- Prithvi
- Agni
- Green Bee
- Sky Horse
- 1980 Stevenson - Wydler Technology Innovation Act
- 1982 Small Business Innovation Development Act
- 1986 Federal Technology Transfer Act
- 1987 Presidential Executive Order 12591
- 1988 Technology Competitiveness Act
MISSION: Facilitate the Transfer of DoD-Funded R&D to the Commercial Market Place and to Other Federal Programs

APPROACH: Implement a Proactive Program to Match Technical Needs with DoD Technologies

OBJECTIVES: • Improve U.S. Industrial Capabilities
• Enhance U.S. Global Competitiveness
• Strengthen U.S. National Security
• Provide Return on Taxpayer's Investment in R&D
SDI TECHNOLOGY TRANSFER

Environment

Transportation

Communications

Brilliant Pebbles

Interceptor Missiles

Advanced Radar

Brilliant Eyes

Computers

Power Sources

Security

BioMedicine

Manufacturing
TECHNOLOGY APPLICATIONS PROGRAMS

- Personal Contact
- Demonstration Programs
- Focused Articles
- Speaking Services

- Reports
- Brochures
- Newsletters

- Federal Laboratory Interaction

- Technology Applications Information System (TAIS)

- Networking

- Technology Applications Review
SDIO OUTREACH

Reference And Specialized Publications

Outreach Data Base

Targeted Mailings

Professional Associations Nationwide

SDI Technology Transfer

Exhibit Materials Meeting Administration

Conference Support

Referral And Assistance

People-to-People Process
National Technology Transfer Center

Cooperative Research and Development Agreements (CDRA)

Conferences and Exhibits

Federal Laboratory Consortium

Interaction with Other Departments and Agencies

International Technology Transfer
  - Modeled After SDIO Technology Applications Program
• Function: Promote Commercialization Of Defense Technology
• Resources Required For
  - Adequate Personnel To Expedite Military / Commercial T²
  - DoD T² Policy And Directives
  - National Database Of Defense Technologies
  - T² Demonstration Projects
  - T² Assistance To Industry, State / Local Governments, And Academia
TECHNOLOGY APPLICATIONS REVIEWS

STANDING PANELS
- Power
- Electronics
- Optics & Sensors
- Biomedical
- Materials

AD HOC PANELS
- Superconductivity
- Environment
- Transportation

A NEW...
- IDEA
- PROCESS
- PRODUCT
- BUSINESS

PANEL MAKEUP
Government • Academia • Industry • Marketing • Venture Capital
- License to Others
- Partnerships
- Joint Ventures
- Spin-off New Companies
- Protect Your Idea
  - Nondisclosure Agreements, Patents, Trademarks, Copyrights, and Trade Secrets.

- Understand the Market and Identify the Competition
  - Perform market analyses to identify potential market size, user needs, players.

- Develop a Business Plan
  - Plan should build upon market analyses and present a sound approach to the market place.

- Implement the "Right" Plan
  - "Right" varies by company, technology, product, market, financing, etc.
  - Continuously measure progress and keep your finger on the market pulse. Be prepared to react to market changes.
TECHNOLOGY TRANSFER CONSIDERATIONS

- Commercial availability and vendor support
- Flexibility to current and future applications
- Process and equipment stability
- Purchase cost
- Maintenance cost
- Installation cost and time
- Adaptive and retrofit functionality
- Integration to existing operations
INDUSTRY ROLE IN GUIDING SDI COMMERCIAL STRATEGY

Representative SDIO Technology Transfer Network

- American Bearing Manufacturers Association (ABMA)
- American Defense Preparedness Association (ADPA)
- American Society of Metals International (ASM Int'l)
- Armed Forces Communications & Electronics Association (AFCEA)
- Electronic Industries Association (EIA)
- Industrial Research Institute (IRI)
- Institute of Electrical and Electronics Engineers (IEEE)
- Manufacturers Alliance for Productivity and Innovation (MAPI)
- National Business Incubators Association (NBIA)
- National Coalition for Advanced Manufacturing (NACFAM)
- National Center for Advanced Technologies (NCAT)
- National Center for Manufacturing Sciences (NCMS)
- National Electrical Manufacturers Association (NEMA)
- National Tooling and Machining Association (NTMA)
Major Features

- Reserves a fraction of the R&D budgets of Federal agencies for smaller Enterprises.
- Establishes Small Business Innovation Research (SBIR) Programs.
- Stressed benefits through job creation as well as technical innovation.
- Bypasses most of the federal competitive review and procurement procedures.
CURRENT PROGRAM:
- 1.25% of Extramural R&D Budget available for SBIR awards

FUTURE PROGRAM:
- 2.5% of Extramural R&D Budget by 1998

FY 93 PROGRAM:
- Funds: Approximately $240M
- Topics: 424 for all DoD Agencies

CONTACT:
Small Business Administration
1-800-225-DTIC or (703) 274-6902
Seeking Creative Ideas for Research Leading to an Improved Strategic Defense System

Proposal

- directed energy
- superconductivity
- kinetic energy
- heat management
- materials
- space power
- sensors
- propulsion
AND OTHERS!

$50,000

Proof of Principle Study

PHASE I
(6 Months)

$500,000

Exploitation

PHASE II
(1-2 Years)

CRITERIA FOR SUCCESS
1. Degree of Innovation
2. Help to SDI
3. Future Market Potential

Federal and Commercial Marketplace
Cooperative Research and Development Agreements (CRADAs)

**IF YOU HAVE**

Technology idea that needs development to be commercial success

**and...**

**A FEDERAL LAB HAS**

- Technology
- Facilities
- People
- Expertise

... and can make them available

**USE A CRADA**

But you can't do all the work yourself

Your people can use lab facilities and equipment, people, and expertise (but can't receive lab funds) while protecting your idea.
## COOPERATIVE RESEARCH and DEVELOPMENT AGREEMENTS (CRADAs)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Defense</td>
<td>2</td>
<td>11</td>
<td>41</td>
<td>113</td>
<td>193</td>
<td>303</td>
</tr>
<tr>
<td>Agriculture</td>
<td>9</td>
<td>51</td>
<td>98</td>
<td>128</td>
<td>177</td>
<td>240</td>
</tr>
<tr>
<td>Commerce</td>
<td>0</td>
<td>9</td>
<td>44</td>
<td>82</td>
<td>115</td>
<td>177</td>
</tr>
<tr>
<td>Energy</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>43</td>
<td>152</td>
</tr>
<tr>
<td>EPA</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>11</td>
<td>31</td>
<td>35</td>
</tr>
<tr>
<td>HHS</td>
<td>22</td>
<td>28</td>
<td>89</td>
<td>110</td>
<td>144</td>
<td>241</td>
</tr>
<tr>
<td>Interior</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>12</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td>Transportation</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td>VA</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>33</td>
<td>99</td>
<td>276</td>
<td>460</td>
<td>731</td>
<td>1,175</td>
</tr>
</tbody>
</table>
**Problem:** How do you get from a prototype technology to a deployed, highly reliable system?
RESULT: An Affordable, Reliable, Deployable Space Defense System
MODIL MANAGERS

- Survivable Optics MODIL
  Bill Martin
  Oak Ridge National Laboratory
  (615) 574-8356
  (615) 574-9407 (Fax)

- Electronics and Sensors MODIL
  Peter Winokur
  Sandia National Laboratory
  (505) 844-3013
  (505) 844-2991 (Fax)

- Spacecraft Fabrication and Testing MODIL
  Ted Saito
  Lawrence Livermore National Laboratory
  (510) 422-1553
  (510) 423-7914

- Software Producibility MODIL
  Arnold Johnson
  National Institute of Science and Technology
  (301) 975-3247
  (301) 590-0932
TECHNOLOGY APPLICATIONS
INFORMATION SYSTEM (TAIS)

- Technology Referral
- SBIR Requirements
- Innovative Science & Technology Topics
- Technology Service Agencies
  - State & Regional
  - Federal
  - Investment Capital Sources
- Federal Technology Resources

A National Technology Transfer System

18,000+ POTENTIAL USERS

2000+ (and growing) UNCLASSIFIED ABSTRACTS
## STATUS OF ALLIED CONTRACTS

<table>
<thead>
<tr>
<th>Country</th>
<th>Number Of Contracts</th>
<th>$Values (M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>United Kingdom</td>
<td>158</td>
<td>150.27</td>
</tr>
<tr>
<td>Germany</td>
<td>49</td>
<td>90.24</td>
</tr>
<tr>
<td>Israel</td>
<td>25</td>
<td>311.07 *</td>
</tr>
<tr>
<td>Italy</td>
<td>25</td>
<td>16.08</td>
</tr>
<tr>
<td>Japan</td>
<td>20</td>
<td>7.10</td>
</tr>
<tr>
<td>France</td>
<td>22</td>
<td>21.15</td>
</tr>
<tr>
<td>Canada</td>
<td>22</td>
<td>14.98</td>
</tr>
<tr>
<td>Belgium</td>
<td>4</td>
<td>0.52</td>
</tr>
<tr>
<td>Denmark</td>
<td>1</td>
<td>0.03</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>3</td>
<td>19.43 **</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>329</td>
<td><strong>$768.00</strong></td>
</tr>
</tbody>
</table>

* Includes $137.160 Million Contribution By Israel  
** Includes $7 Million Contribution By The Netherlands
TECHNOLOGY TRANSFER
LESSONS LEARNED

A Responsive Methodology
- Person-to-Person ... NOT Data to Person
- Easy, Low Cost, Efficient Access

A Proactive Approach
- Technology Push
- Market Pull
- Tracking and Follow-up

Leads to ...
- Increased U.S. Productivity
- Increased U.S. Competitiveness in the World Marketplace

A PEOPLE TO PEOPLE PROCESS
# Ballistic Missile Defense Organization

## Federal Technology Transfer (T²) Points of Contact

<table>
<thead>
<tr>
<th>Department of Defense</th>
<th>DOC / NIST (ATP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Army - Cliff Lanham</td>
<td>- George Uriano</td>
</tr>
<tr>
<td>- (301) 394-4210</td>
<td>- (301) 975-5187</td>
</tr>
<tr>
<td>- Navy - Ron Culpepper</td>
<td>- BMDO - Nick Montanarelli</td>
</tr>
<tr>
<td>- (703) 696-4448</td>
<td>- (703) 695-3891</td>
</tr>
<tr>
<td>- Air Force - Chuck Chatlynne</td>
<td>- ARPA - Rick Dunn</td>
</tr>
<tr>
<td>- (703) 693-1671</td>
<td>- (703) 696-2407</td>
</tr>
<tr>
<td>- DTIC - Dave Appler</td>
<td>- DTIC - Dave Appler</td>
</tr>
<tr>
<td>- (703) 274-9313</td>
<td>- (301) 243-2456</td>
</tr>
</tbody>
</table>

## National Technology Transfer Center

<table>
<thead>
<tr>
<th>National Technology Transfer Center</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Thomas Clinton</td>
</tr>
<tr>
<td>- (304) 243-2456</td>
</tr>
<tr>
<td>- (800) 678-NTTC</td>
</tr>
</tbody>
</table>

## Federal Laboratory Consortium

<table>
<thead>
<tr>
<th>Federal Laboratory Consortium</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Dr. Andy Cowan</td>
</tr>
<tr>
<td>- (206) 683-1005</td>
</tr>
</tbody>
</table>
I WANT YOU TO
THINK SPINOFFS!

STRATEGIC DEFENSE INITIATIVE
DEPARTMENT OF DEFENSE
TECHNOLOGY TRANSFER
AND
VENTURE CAPITAL

PRESENTED BY:

BARRY M. WEINMAN
GENERAL PARTNER OF NEWTEK VENTURES
FINANCING TECHNOLOGY DEVELOPMENT AGENDA

I. INTRODUCTION
NEWTEK VENTURES
BARRY WEINMAN

II. TRADITIONAL METHODS

III. VENTURE CAPITAL

IV. SOME OTHER IDEAS
# INTRODUCTION TO NEWTEK VENTURES

- **FOUNDED:** March 1983
- **$$ MANAGED:** Over $60M
- **INTEREST:** Early stage high-tech, breakeven and poised for change
- **CRITERIA:** Excellent management, compelling market, high margin product or service, focus & sense of urgency, "unfair advantage"
- **INITIAL $$:** $250K to $1M, plus syndication help
- **PORTFOLIO STATUS:** 36 companies, 9 IPO's, 1 acquisition, 3 write-offs, a few sickies
BARRY WEINMAN

B.S. CLARKSON UNIVERSITY
M.A. UNIVERSITY OF SOUTHERN CALIFORNIA

“BIG COMPANY”

AT&T MANAGEMENT TRAINEE
U.S. NAVY OPERATIONS OFFICER
FAIRCHILD SPEECHWRITER
IBM SEMICONDUCTOR PRODUCTION MARKETING

“SMALL COMPANY”

IAI FOUNDER, CEO
BATTERY MANUFACTURING SOFTWARE
SYSTEMS FOUNDER, PRESIDENT

BATTERIES NICKEL-ZINC BATTERY

NEWTEK VENTURES TURN-AROUNDS

PHASE II AUTOMATION
HERE TEST EQUIPMENT
KEY LOGIC SYSTEMS SOFTWARE

BOARD OF DIRECTORS RESPONSIBILITIES

HUNTER SYSTEMS
KEY LOGIC
NEXT CENTURY POWER
PALM COMPUTING
BE, INC.
TRADITIONAL SOURCES

I. R & D

SBIR GRANTS
DARPA
NIH
DOE
NSF

CORPORATIONS
DIRECTED DEVELOPMENT
GREYHAWK
CHOLESTECH

II. PRODUCTIZATION

STRATEGIC PARTNERS
CONNOR PERIPHERALS
NEUREX

BIRD FOUNDATION
HUNTER SYSTEMS

III. MARKET READY

VENTURE LEASING
RECEIVABLES FINANCING
JOINT VENTURES
# VENTURE CAPITAL STATISTICS

<table>
<thead>
<tr>
<th>Industry Size:</th>
<th>644 Firms</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Professionals:</td>
<td>Approx. 2,000 (1/2 Partners)</td>
</tr>
<tr>
<td>Growth Rate:</td>
<td>4.4%</td>
</tr>
<tr>
<td>Money Raised:</td>
<td></td>
</tr>
<tr>
<td>1989:</td>
<td>$2.4B</td>
</tr>
<tr>
<td>1991:</td>
<td>$1.8B</td>
</tr>
<tr>
<td>1992:</td>
<td>$1.3B</td>
</tr>
<tr>
<td>1993:</td>
<td>$2.3B</td>
</tr>
<tr>
<td>Commitments:</td>
<td></td>
</tr>
<tr>
<td>1989:</td>
<td>$3.4B (1,600 Deals)</td>
</tr>
<tr>
<td>1990:</td>
<td>$1.9B (1,018 Deals)</td>
</tr>
<tr>
<td>1991:</td>
<td>$2.0B (1,200 Deals)</td>
</tr>
<tr>
<td>1992:</td>
<td>$2.5B (1,207 Deals)</td>
</tr>
</tbody>
</table>

1993 Available $ Pool: $29.5B
VENTURE CAPITAL DOLLARS RAISED BY YEAR

Dollars (Billions)

*Through June 1993.

Source: Venture Economics
VENTURE CAPITAL PROCESS
(KISSING LOTS OF FROGS)

I. WE RAISE MONEY

II. WE INVEST -- MIND'EM
   A. FIND DEALS
   B. STRUCTURE TERMS & CONDITIONS
   C. HELP DEVELOP VALUE

III. RETURN CAPITAL & PROFIT

IV. RAISE NEW FUND OR CHANGE CAREERS
WHAT VENTURE CAPITALISTS LOOK FOR IN A COMPANY

✓ EXPERIENCED MANAGEMENT

✓ SENSE OF URGENCY!!!

✓ COMPELLING MARKET

✓ STRATEGIC FOCUS

✓ TECHNICAL EXCELLENCE

✓ REASONABLE FINANCING

✓ EXIT STRATEGY
VENTURE CAPITALISTS WILL

- Hire & Fire the CEO
- Help set strategic direction for the company
- Make introductions to financial, business and other potential contacts useful to the company
- Lead future financings
- Assist the CEO think through how to grow the company

VENTURE CAPITALISTS WILL NOT

- Run the company
- Define new products
- Set the organization structure
- Prepare business plans
- Be involved in day-to-day operations
FIRST RULE OF INVESTING

MANAGEMENT
MANAGEMENT
MANAGEMENT

WORKED TOGETHER
• "CHEMISTRY"
• ACKNOWLEDGE LEADER
  CLEAR CUT RESPONSIBILITY/ AUTHORITY

BUILT A COMPANY

SIGNIFICANT PERSONAL INVESTMENT
• ENTREPRENEURS AS INVESTORS
• HOW MUCH IS YOUR CAR WORTH?

BUILD ON PREVIOUS EXPERIENCE
• DO IT RIGHT
• BE FOCUSED

NEWTEK VENTURES
ACHIEVING RETURN ON INVESTMENT

- DEFENSIBLE AND PROFITABLE BUSINESS (NOT JUST A PRODUCT)
- AN EXCELLENT MANAGEMENT TEAM (EXPERIENCED, FLEXIBLE, TENACIOUS AND HONEST)
- ABILITY TO "EXIT" THE INVESTMENT (IPO, ACQUISITION, ETC.)
- FAIR INITIAL PRICING (VALUATION) OF THE COMPANY
- A GROWTH PLAN YIELDING A 10X RETURN ON INVESTMENT IN 5 YEARS (60% PER YEAR COMPOUNDED)
SOME OTHER IDEAS

CONNECT: UCSD
TECHNOLOGY FORUMS
MEET THE RESEARCHER
SEMINARS: MANAGING HIGH TECH START-UPS

AEA UNIVERSITY ASSOCIATES PROGRAM
PARTNERSHIP TO LEVERAGE RESEARCH
AEA R&D FORUM

STANFORD PROGRAM
PARTNERING:
CONSULTING / PART-TIME WORK
LICENSED

PUBLIC DOMAIN CONCEPT (PROTOCOL ENGINES)
LICENSE: FREE AND NON-EXCLUSIVE
TECH FORUM: $25K/YEAR $500/SESSION
CONSULT: EXPERTS IN TECH
EQUITY IN START-UPS
NEWSLETTER SUBSCRIPTION
WORKING GROUP REPORTS
WORKSHOP ON COMMERCIALIZATION OF PULSED POWER SCIENCE AND TECHNOLOGY
San Francisco, CA, August 18-19, 1993

Working Group on Medical, Materials, Other

Participants

Gunter Hofmann  BTX
Tom Naff         P.I.
Kris Kristiansen TTU
Gabriel Roy      ONR
Nick Montanarelli BMDO
Roseanne Dutton  USC
Wayne Hofer      DOE/LLNL
EXCITING OPPORTUNITIES FOR PULSED POWER IN MEDICINE AND MATERIALS ... BUT NEED TO ADAPT, COMMUNICATE, AND ORGANIZE

- Applications
- Cultural issues
- "Packaging" the technology
- "Selling" the technology
- A success story
APPLICATIONS:

Medical

- Imaging - P.E.T., ultrasound, FEL
- Lasers - burn treatment, tattoo removal, photodynamic therapy, plastic surgery, bone cutting, and healing
- Dry sterilization (plasmas, ionbeam)
- Surface treatment (surgical instruments)
- Electroporation
- Pulsed lithotripsy - focused shockwaves
- Waste treatment:
  - e-beam
  - x-ray
  - microwave

Materials/Other ... welding, surface treatment, sub-terrainean radar, treatment of mixed waste, biofouling

The medical customer is different than the U.S. government!
CULTURAL ISSUES:

- The "human factor" - hesitation or unwillingness to risk
- NIH (not invented here) factor
- Proper credentials - "MD"
- Time-lag to acceptance - may be necessary to "start off-shore"
- Liability
- Regulatory agencies
"SELLING THE TECHNOLOGY" TO A SOMETIMES WARY CUSTOMER:

- Work through medical schools, trade associations, and professional societies
- Publish and promote in trade journals
- Participate in medical conferences and seminars
- "Special issues" of leading publications
- Recruit/convert an MD/PhD who likes advertising and R&D ..."the thought leaders"
- Work with Health Industry Manufacturing Association (HIMA)
- Industrial/University recruit Congress
- Identify industry pull
PACKAGING THE TECHNOLOGY IS CRUCIAL:

- Need a new, readily comprehended technology descriptor - not "pulsed power"

- Clearly identify the differentiators:
  - may need x100 improvement
  - an entirely new capability

- User-friendly - not "high-tech":
  - reliable
  - easy to set up and maintain
  - customer focused
WORKSHOP ON COMMERCIALIZATION OF PULSED POWER SCIENCE AND TECHNOLOGY
San Francisco, CA, August 18-19, 1993

Working Group on Environmental Applications

Participants

Jeffrey M. Cukr
Defense Nuclear Agency

George B. Frazier
Physics International

Mike Grothaus
Naval Surface Warfare Center

Myron Jones
Electric Power Research Institute

David A. Goerz
Lawrence Livermore National Laboratory

George F. Kirkman
Integrated Applied Physics

Axel Wolf Kratel
California Institute of Technology

Kenneth R. Prestwich
Sandia National Laboratories

Bernie M. Penetrante
Lawrence Livermore National Laboratory

Karl H. Schoenbach
Old Dominion University

Howard W. Shaffer
Westinghouse Electric Corporation

Leonard T. Whitlock
Oceaneering Technologies
Sampling of Participants' Objectives

- get ideas that may lead to new business

- interested in diversifying and broadening business base in pulsed power; environmental applications is one of new target areas

- find out where the pulsed power community is headed

- gather opinions on the best way to get the technology to the market

- learn about the capabilities of the pulsed power community and match them with the needs of various industries

- seek new opportunities; find how national labs, industry and universities can cooperate

- find out about the capabilities of the pulsed power community, with special interest in groundwater treatment

- gather information and learn the state of the art in pulsed power, with interest in the remediation of ground water

- interest in expanding funding programs on environmental pulsed power applications
COMMENTS

• the urgent environmental applications of pulsed power are already known to most people

• there are already on-going activities resulting from the community's effort to survive
  • we have to change this
    • Survival should not be the goal. It should be the by-product.

• there is a lack of data and understanding to convince the users that pulsed power is the right solution

• there is a need for comparison of technologies, and an open and honest discussion of the best solution

• Is the solution really pulsed power?
APPLICATION OF PULSED POWER TO
NON-THERMAL PLASMA PROCESSING

Needs

• pulsed power generators for pulsed corona
• accelerators for pulsed electron beam
• power modulators for dielectric barrier discharge
• concepts for atmospheric-pressure microwave discharge

Applications

• simultaneous NO\textsubscript{x}/SO\textsubscript{2} removal in power plant flue gas
• NO\textsubscript{x} control in internal combustion engines
• treatment of volatile organic compounds in industrial off-gases
• demilitarization of high explosives
• water treatment

Issues

• power consumption
• capital cost
• lifetime and reliability

Novel Concepts

• hybrid types of plasmas
• pulsed discharge = e-beam with bad emittance?
APPLICATION OF PULSED POWER TO NON-THERMAL PLASMA PROCESSING

Whether e-beam or discharge, pulsing is the means for attaining high power and high electron energies.

• high power required because of large volume flow rates

• high electron energies required in order to increase processing efficiency
DEVELOP RELATIONSHIPS that will help us find commercial markets for pulsed power.
Focus on a specific goal that will accelerate the development and application of pulsed power for environmental applications.

CULTURAL CHANGE IS NEEDED

• if this technology is so wonderful, how come industry is not craving for it
• we still need to sell the technology to the users

DEVELOP A SENSE OF URGENCY

Invest in pilot plant demonstrations to show that DOE, DOD and industry are serious about this technology.

• concentrate on applications with requirements that can be met with existing or near-existing technologies
  • e.g., industrial boilers instead of utility power plants
APPLICATION OF PULSED POWER TO AIR POLLUTION CONTROL

HOW BIG IS THE MARKET?
In the US alone, the total emission of NO\textsubscript{x} amounts to 24 million tons per year. About 53% of this is emitted from utility and industrial fuel combustion. The Clean Air Act of 1990 demands that the NO\textsubscript{x} emissions be reduced to 2 million tons per year (92% reduction).
Even with particulate removal devices having an average removal efficiency of 99%, the worldwide emission to the atmosphere is still 30 million tons of solid particulates per year. Forecasts suggest that by year 2000, the world coal consumption will increase by 35%. To keep the total emissions of solid particulates constant, the collection surface of electrostatic precipitators have to be doubled.

Simplest form of an electrostatic precipitator. When a high voltage is applied to the wire, the electric field created produces a corona region consisting of electrons and ions. The drift field established between the corona region and the collection plate extracts ions. These ions interact with the particulates, imparting charge to the dust which is then driven to the collecting plate. Maximum particle collection requires maximum charges on the particles and maximum precipitation fields. Large particle charges can be attained only by applying very high peak voltages, while rapid collection of the charges requires high time-averaged values of the voltage.
APPLICATION OF PULSED POWER TO FLUE GAS CLEANUP

Simplified model of reaction mechanisms for the simultaneous removal of SO\textsubscript{2} and NO\textsubscript{x} from flue gas by electron beam irradiation. Stage 1 represents radical production from the interaction of electrons with the flue gas. Stage 2 represents the conversion of SO\textsubscript{2} and NO\textsubscript{x} to their respective acids, and the reduction of NO to N\textsubscript{2}. Stage 3 represents the formation of salt by-products which are then collected by an electrostatic precipitator or baghouse. The same mechanisms apply to the pulsed corona process, but the relative amounts of initial radicals and final by-products are different because the mean electron energies are lower.
APPLICATION OF PULSED POWER IN ELECTROSTATIC PRECIPITATORS

Pulsed systems could be used to optimize precipitator efficiency by allowing one to precisely adjust and control both the duration and frequency of the current pulses. The use of pulsed power makes it possible to achieve higher peak voltage and higher sparking voltage.

Pilot plant tests in the US, Japan and Italy showed that the use of pulsed power leads to an increase in the precipitation efficiency without having to increase the area of the collecting electrodes. Furthermore, pulsed powering leads to a higher over-all electrical efficiency.

Pulsed power will become more important for particulate control as the world consumption of coal increases.
PILOT PLANT RESULTS ON ELECTRON BEAM AND PULSED CORONA FLUE GAS TREATMENT

Amount of NO\textsubscript{X} removed as a function of the specific energy input. The pulsed corona result obtained at ENEL (Italy) was for initial NO\textsubscript{X} of 300-550 ppm, and gas flow rates of 500-600 Nm\textsuperscript{3}/h. The electron beam result obtained at Ebara (USA) was for initial NO\textsubscript{X} of 270-390 ppm, and gas flow rates of 4000-5200 scfm. The result obtained at Ebara (Japan) used 3-stage electron beam irradiation with initial NO\textsubscript{X} of around 200 ppm. The result obtained at JAERI (Japan) used triple stage irradiation with initial NO\textsubscript{X} of 150 ppm and gas flow rate of 15 Nliter/min.
POWER REQUIREMENT OF
ELECTRON BEAM FLUE GAS TREATMENT

500 MW power plant
burning 194 tons per hour of midwestern coal.

Typical flue gas flow rate is $10^6$ scfm or $4.7 \times 10^8$ cm$^3$/s.

The gas is polluted with 350 ppm of NO$_x$ and 2000 ppm of S0$_2$.

Both laboratory and pilot plant tests show that it is relatively easy to remove S0$_2$. The power consumption for the combined removal of NO$_x$ and S0$_2$ is determined mainly by the removal of NO$_x$.

The required rate of NO$_x$ removal is

$$350 \text{ ppm} \times 10^{-6} \times 4.7 \times 10^8 \text{ cm}^3/\text{s} \times 2 \times 10^{19} \text{ molecules/s} = 3.3 \times 10^{24} \text{ NO}_x\text{-molecules per second}$$

The best value of specific energy consumption for deNO$_x$ achieved by the electron beam process is

$$14 \text{ eV/NO}_x\text{-molecule} \quad (\text{deNO}_x \text{ by e-beam}).$$

The power requirement for the electron beam process is thus

$$14 \text{ eV/NO}_x \times 3.3 \times 10^{24} \text{ NO}_x/\text{s} = 4.6 \times 10^{25} \text{ eV/s} = 7.4 \text{ MW}$$

This represent 1.5% of the power plant output.
POWER REQUIREMENT OF
PULSED CORONA FLUE GAS TREATMENT

500 MW power plant
burning 194 tons per hour of midwestern coal.

Typical flue gas flow rate is $10^6$ scfm or $4.7 \times 10^8$ cm$^3$/s.

The gas is polluted with 350 ppm of NO$_x$ and 2000 ppm of SO$_2$.

Both laboratory and pilot plant tests show that it is relatively easy to remove SO$_2$. The power consumption for the combined removal of NO$_x$ and SO$_2$ is determined mainly by the removal of NO$_x$.

The required rate of NO$_x$ removal is

$$350 \text{ ppm} \times 10^{-6} \times 4.7 \times 10^8 \text{ cm}^3/s \times 2 \times 10^{19} \text{ molecules/s} = 3.3 \times 10^{24} \text{ NO}_x\text{-molecules per second}$$

The best value of specific energy consumption for deNO$_x$ achieved by the pulsed corona process is

50 eV/NO$_x$-molecule (deNO$_x$ by pulsed corona).

The power requirement for the pulsed corona process is thus

$$50 \text{ eV/NO}_x \times 3.3 \times 10^{24} \text{ NO}_x/s = 1.7 \times 10^{26} \text{ eV/s} = 26.4 \text{ MW}$$

This represent 5.3% of the power plant output.
COSTS OF FLUE GAS TREATMENT USING ELECTRON BEAM AND PULSED CORONA

Cost analysis shows that in order for electron beam processing to be competitive with the FGD/SCR method, the accelerator has to cost around $2 per watt.

A 500 MW power plant will require a 7.4 MW accelerator (or set of accelerators) costing $15 million.

Assuming that pulsed power generators can be manufactured at a cost of $1 per watt, the same 500 MW power plant will require a 26.4 MW pulsed power system costing $26 million.
LESSONS FROM HISTORY

(1) Pulsed power has already been successfully demonstrated in a large scale for improving the efficiency of electrostatic precipitators. Pulsed power will undoubtedly become essential as the world consumption of coal for energy production increases.

(2) Many pilot plant tests of electron beam processing for NO$_x$/SO$_2$ removal have been, and continue to be, conducted around the world. Coal-fired pilot plant tests with gas flow rates as large as 25,000 Nm$^3$/h have been conducted. Scale-up of electron beam accelerators using pulsed techniques are now being conducted. The use of pulsed electron beams is essential to meet the beam power requirements and to reduce the cost of the accelerators.

(3) Demonstration of the pulsed corona process for NO$_x$/SO$_2$ removal in a large scale has been hampered by the absence of suitable pulsed power generators. The pulsed power requirements for pulsed corona reactors are much more demanding than those for electrostatic precipitators. The largest pilot plant test conducted using pulsed corona is only 1,000 Nm$^3$/h. Larger scale tests are essential to learn not only what the scalability of the process is, but also what the typical investment and operating costs are at full-scale industrial facilities.
REFERENCES


"Economics of Electron Beam and Electrical Discharge Processing for Post-Combustion NO\textsubscript{X} Control in Internal Combustion Engines", B. M. Penetrante, Proceedings of the 6th BMDO/ONR Pulse Power Meeting, Chicago, IL (August 1993).

Non-Thermal Plasma Techniques for Pollution Control, edited by B. M. Penetrante and S. E. Schultheis
Volume 1 - Overview, Fundamentals and Supporting Technologies
Volume 2 - Electron Beam and Electrical Discharge Processing
WHAT SHOULD THE RESOURCE GROUPS DO TO HELP THE COMMERCIALIZATION OF PULSED POWER SCIENCE & TECHNOLOGY?

HOW TO BE IN TOUCH WITH THE WORLD/CUSTOMERS BETTER?

MATCHING APPLICATIONS/MARKETS TO TECHNOLOGIES
MORE INTERACTIONS BETWEEN INDUSTRY AND UNIVERSITY:

- INFLUENCE FACULTY RESEARCH INTEREST
- EXPOSES STUDENTS EARLY TO THE PROBLEMS AND CHALLENGES
- GOVERNMENT COULD PROVIDE POST-GRADUATE FELLOWSHIP TO ENCOURAGE INTERACTIONS

MORE INTERACTIONS BETWEEN INDUSTRY AND NATIONAL LABORATORIES

WHAT SHOULD THE INDUSTRY DO?
Universities have demonstrated successful industrial spin-offs, e.g. Silicon Valley

Faculties could improve communications to the world on merits of pulsed power technology, e.g. by writing more articles to trade journals as opposed to professional journals

Change performance measures for the faculties

Industrial advisers on graduate students thesis committees

Modify degree requirements to reflect more real world problems

Mandatory internship programs

Attract industrial usage of university facilities & resources through formalized effort

What should the universities do?
WORK ON PROBLEMS THAT MAY BE TOO COSTLY FOR INDUSTRY TO UNDERTAKE, e.g. RELIABILITY/LIFE IMPROVEMENT/TESTING

EMPLOYEE EXCHANGE PROGRAMS WITH INDUSTRY AND UNIVERSITY:

- PROMOTE CULTURE AND TECHNOLOGY EXCHANGE
- A FAIR EXCHANGE WILL ELIMINATE THE CONCERN OF LABS PROVIDING FREE LABOR TO INDUSTRY

WHAT SHOULD THE GOVERNMENT LABS DO?
CONTINUE TO EMPHASIZE DUAL USE

ADOPT SUCCESS IN PROMOTING DUAL USE AS A CRITERION FOR BONUS IN MERIT PAY SYSTEM FOR FUNDING AGENCY EMPLOYEES

DEVELOP METRIC FOR DUAL USE PERFORMANCE

WHAT SHOULD GOVERNMENT FUNDING AGENCIES DO?
MORE PARTICIPATIONS FROM NOT-FOR-PROFIT ORGANIZATIONS (e.g. EPRI, American Water Works Association, National Gas Research Institute, etc.) IN WORKSHOPS TO DISCUSS APPLICATIONS

WHAT SHOULD THE NOT-FOR-PROFIT ORGANIZATIONS DO?
MORE SERIOUS PARTICIPATION IN INTERNATIONAL CONFERENCES/WORKSHOPS THAT ARE NOT RELATED TO PULSED POWER

MAKE ASSESSMENTS OF TRENDS AND TECHNOLOGY MORE READILY AVAILABLE

BE PROACTIVELY EXPOSED TO OTHER AREAS

FORM STRATEGIC PARTNERSHIPS BETWEEN DIFFERENT INDUSTRIES

HOW TO BE IN TOUCH WITH THE WORLD/CUSTOMER BETTER?
REFER TO PAPER:
"COMMERCIAL APPLICATIONS FOR MODULATORS AND PULSE POWER TECHNOLOGY"
BY S. LEVY, M. NIKOLICH, I. ALEXEFF, M. RADER, M.T.
BUTRAM, AND W.J. SARJEANT