WHITE PAPER ON THE ARMOR/ANTI-ARMOR PROGRAM

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Submitted to:
Dr. Harry Fair
Assistant Director for Land Warfare
Defense Advanced Research Projects Agency

In Response To
Armor/Anti-Armor
Briefing to Industry
At Naval Surface Weapons Center
White Oak, MD
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Introduction

The Center for Electromechanics of the Bureau of Engineering Research at The University of Texas at Austin (CEM-UT) proposes to support DARPA, the U.S. Army and the U.S. Department of Defense in undertaking the fast track Armor/Anti-Armor development program as briefed to industry on January 29, 1986 at the Naval Surface Weapons Center in White Oak, MD. CEM-UT has been active in developing rotating electrical machines for pulsed power generation since 1972 and in the development of electromagnetic railguns since 1979. Both of these technologies are felt to be crucial to the success of the kinetic energy weapon aspect of the proposed program. Since CEM-UT is a not-for-profit, hardware-oriented research and development center operated by a public university, its staff can provide counsel, guidance, and evaluation of alternatives unbiased by commercial considerations as well as the technical expertise necessary to insure the success of the program.

Although willing to serve in any capacity desired by the sponsors, consistent with its charter, CEM-UT proposes specifically to participate in three areas. These are

- KINETIC ENERGY WEAPONS
- INTEGRATED SYSTEMS
- COMPETITIVE EVALUATION ACTIVITY.

Although CEM-UT expertise relevant to kinetic energy weapons is generally well known to the sponsors, it is briefly summarized in this white paper. A primary role in the integrated systems area is not proposed, since this role seems more
appropriate for a weapon systems integrator or vehicle builder. However, a tactical vehicle with a turbine-powered generator capable of driving an electromagnetic (EM) gun seems to be an ideal candidate for a vehicle with an electric drive powered from the same source. Since generators developed by CEM-UT are among the prime candidates for tactical EM gun power supplies and the generators and vehicle drive systems will have to be designed as integrated systems, CEM-UT proposes to participate in this activity even to the point of prototyping components and subsystems.

Finally, the Competitive Evaluation Activity (CEA) is the heart of the proposed Armor/Anti-Armor program. It is important that it be operated by a group independent from the commercial manufacturers of components and systems and yet of unquestioned technical competence and integrity. As a minimum, the CEA must offer the following.

- Full capability gun range
- Laboratory testing of devices (weapons and armor)
- Contracting authority for the program
- Design of tests and analysis and evaluation of test results
- Documentation, reporting, briefings, and technical seminars for program participants

Since it is unlikely that a single entity can provide the desired level of expertise in all areas, CEM-UT has initiated discussions with a number of potential team members regarding their participation on an overall CEA team headed by The University of Texas. This activity is also discussed in this document.
CEM-UT Background

The Center for Electromechanics at The University of Texas at Austin (CEM-UT) originated in 1972 with an informal investigation of inertial energy storage using homopolar conversion as a source of pulsed power for controlled thermonuclear fusion experiments. The homopolar generator, an inexpensive, versatile and simple electromechanical machine, stores kinetic energy by slowly bringing to speed a rotating flywheel and then rapidly converting that stored energy to electrical energy at very high power levels -- millions of watts for a second or less. Initially, a 0.5 megajoule machine was designed and built to prove feasibility. In 1974 the Center developed a 5 megajoule homopolar generator which was later upgraded to 10 megajoules of stored energy. This machine is now used on virtually a daily basis to provide pulsed power for a variety of experiments in the CEM laboratory. Its success led to the formation of an Industrial Applications Group within CEM. The major projects of the Industrial Applications Group include homopolar pulse resistance welding, heating, and sintering.

In 1976 CEM participated in a study to design a 1,000 megajoule fast discharging homopolar generator to power the toroidal field coils of a theta-pinche fusion device. A 350 kilojoule model machine, the Fast Discharge Experiment, which operated at a 4-tesla average magnetic field and demonstrated a 400 microsecond rise-time to peak current was built.
CEM-UT's emphasis on pulsed power supply research for controlled
thermonuclear fusion expanded in 1978 to include a new type of rotating
electrical machine invented by CEM engineers, the compensated pulsed
alternator (compulsator). The compulsator, which is unique in its abi-
licity to produce a repetitive burst of high power pulses, appears to be a
promising alternative to conventional electrostatic capacitor banks. A
prototype compulsator rated at 6,000 volts and 60,000 amps was built and
tested. It powered a xenon flashlamp system from a solid-state laser,
delivering 140 kilojoules in 0.0013 seconds. In addition, the rotary
flux compressor, a first cousin of the compulsator, demonstrated a flux
compression ratio of 47:1 during tests.

Interest in the railgun, an electromagnetic accelerator which is
the linear equivalent of a homopolar generator, began to rise at CEM in
1979 when William F. Weldon, then the Center's Technical Director,
served on a Department of Defense Electromagnetic Launch Advisory
Committee. CEM has participated in the United States Electromagnetic
Propulsion Program by developing both power supplies and accelerators.
Early in the program it was recognized that the central issue to all
interesting electromagnetic launch applications is the size and type of
the power source. Homopolar generators were identified as the energy
store with the greatest near-term potential. In 1980 CEM began a
program to develop a compact, high energy, high current pulsed power
supply. The power supply consists of a compact homopolar generator for
primary energy storage, a cryogenic coaxial inductor for power con-
ditioning and an opening switch for energy transfer from the power supply to the accelerator. The compact homopolar generator, a 50-volt, 1-million ampere power supply, weighs 3,400 pounds and stores 6.2 megajoules of kinetic energy. It delivers half of its energy to the inductor at rated current. The machine was selected by Industrial Research and Development as one of the 100 most significant new technical products of 1983. It has been licensed for production to industry by The University of Texas and the first production model has been delivered.

During 1984 and 85, The University of Texas at Austin pursued an aggressive expansion of the Balcones Research Center and built for CEM-UT a superb facility with 40,000 square feet of office space, a 70-foot high, 60-foot wide, 420-foot long experimental high bay, many large labs and an excellent machine shop. A description of the new Balcones facility is included in Appendix A.

CEM-UT has built, and is now operating, three generations of homopolar generators (HPG). The first generation is a 5-megajoule machine which was built in 1974. It was rebuilt and its rating increased to 10 MJ in 1979 and since then has been operating on a routine basis as a laboratory power supply for a variety of experiments. The All-Iron-Rotating (A-I-R) HPG is the second generation of HPGs built at CEM. It is the state-of-the-art compact, high energy-density, pulsed-HPG power supply. Weighing 3,400 pounds, the A-I-R HPG stores 6.2 megajoules and produces 1.0-megampere discharge current. A cryoge-
nic, coaxial inductor, which stores 3.1 megajoules at 1.0 megampere, was 
built to provide an appropriate load for the A-I-R HPG, as well as power 
conditioning for a railgun. At this time, experiments are being con-
ducted on a two-stage, 1.0-megampere, 10-microsecond commutation-time 
opening switch using the A-I-R HPG/Coaxial Inductor as a power supply. 
When these experiments are completed, the system will be used to power a 
railgun. Finally, a third generation HPG, called the HPG System Tester, 
was built and is operating. This machine is a test bed for the develop-
ment of components needed to extend the state of the art of compact, 
high energy density HPGs. Components being developed include very high 
slip speed, cooled brushes, stationary shaft hydrostatic bearings, 
integrated motoring drives, and self-excited field coils.

In addition, CEM engineers have designed, fabricated and are 
assembling components of the rotor and stator subassembly of a 500-volt, 
500-kiloampere, 3.25-megajoule, HPG. The rotor subassembly, which 
includes an aluminum rotor, brush assemblies, bearing stator, and an 
appropriate load, will be installed in the warm bore of a 5-tesla super-
conducting field coil which is being built by G. A. Technologies. 
Experiments on this high-voltage HPG (HV/HPG) are scheduled for April 
1986.

CEM is nearing completion on a 60-megajoule HPG power supply. This 
power supply consists of six, 10-megajoule, 100-volt, 1.5-megampere 
machines which can be connected electrically in series or parallel to
result in 600-volt, 1.5-megampere or 100-volt, 9.0-megampere performance characteristics. A 240 Hz, 2500 volt 1-MA Compulsator power supply is also being prepared for testing during 1986.

During the past five years, CEM-UT Has contributed the following concepts and experiments to railgun accelerator technology:

- Demonstrated the first railgun with the projectile being injected into the brech to minimize rail damage.

- Invented the distributed energy store (DES) railgun. Built and tested a 4-meter long DES railgun to verify improved performance and efficiency.

- Provided Vought Corp. with conceptual design of a simple railgun with an injected projectile which accelerated a 3- to 5-gram projectile up to 8 kilometers per second. Also provided Vought Corp. with a conceptual design of their high efficiency DES railgun.

- Demonstrated a round-bore augmented railgun for 80-gram projectiles which had an effective inductance gradient greater than 1 microhenry (μH) per meter.

- Built and tested the original GEDI railgun which operated in a hard vacuum with plasma armatures at velocities in the 20- to 40-kilometers per second range.
- Built and tested 1-m and 2-m long square bore, 5 kbar railguns capable of accelerating 1-2 gm projectiles to 5 and 7.5 km/s respectively.

Computer codes have been written and verified with experimental data for all of these devices. Appendix B provides a list of recent CEM-UT related research experience.
Kinetic Energy Weapons

The electromagnetic railgun offers the prospect of higher velocities with controlled acceleration, reduced vulnerability, logistics burden, and man-power requirements for tactical weapon systems. A limiting factor in the implementation of EM guns has been the size and weight of the power supplies necessary to operate them. Recent technical developments in several areas offer the promise of practical EM gun weapons with capabilities substantially above current conventional guns. The most promising candidate power supplies are considered to be

- Compulsators
- Homopolar Generators
- Capacitors.

Of the three, two have been under development at CEM-UT for a substantial length of time. Research and development efforts on homopolar generators started at CEM-UT in 1972. Table 1 gives the parameters of homopolar generators built or now under development at CEM-UT.

The last entry in Table I, the self excited, air-core homopolar generator, includes several innovations which promise to reduce its weight and volume to a point where it will be attractive for tactical weapon system applications. It features fiber reinforced, epoxy matrix rotor and stator construction for improved energy density, separation of energy storage and power generation functions for component optimization, and integration of excitation windings with the energy storage inductor for improved performance with reduced bulk. Conceptual design of this machine
<table>
<thead>
<tr>
<th>Machine Type</th>
<th>PROOF-OF-PRINCIPAL HPG</th>
<th>CEM-HPG</th>
<th>FAST DISCHARGE HPG</th>
<th>COMPACT HPG</th>
<th>HPG SYSTEMS TESTER</th>
<th>BALCONES HPG</th>
<th>HIGH-VOLTAGE HPG</th>
<th>SELF-EXCITED AIR-CORE HPG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stored Energy (MJ)</td>
<td>0.5</td>
<td>5/10</td>
<td>0.35</td>
<td>6.2</td>
<td>5</td>
<td>6 x 10</td>
<td>3</td>
<td>240/130</td>
</tr>
<tr>
<td>Output Voltage (V)</td>
<td>20</td>
<td>40/47</td>
<td>200</td>
<td>50</td>
<td>25</td>
<td>6 x 100</td>
<td>500</td>
<td>450/10,000</td>
</tr>
<tr>
<td>Output Current (MA)</td>
<td>0.014</td>
<td>0.4/0.8</td>
<td>0.2</td>
<td>1.5</td>
<td>1.0</td>
<td>6 x 1.5</td>
<td>0.5</td>
<td>3.2</td>
</tr>
<tr>
<td>Current Rise Time (ms)</td>
<td>50</td>
<td>50</td>
<td>0.4</td>
<td>17</td>
<td>18</td>
<td>20</td>
<td>0.2</td>
<td>0.01</td>
</tr>
<tr>
<td>Weight (tonnes)</td>
<td>4</td>
<td>7</td>
<td>0.5</td>
<td>1.7</td>
<td>0.3</td>
<td>6</td>
<td>6</td>
<td>2.5</td>
</tr>
</tbody>
</table>
known as the Improved Energy Density Homopolar Generator (IED-HPG) is presently funded with support for detailed design anticipated from FY 1986 funds. The original IED-HPG proposal is included in Appendix C of this white paper.

The compulsator, the most promising rotating-machine power supply for EM gun weapon systems, was invented at CEM-UT in 1978. Since that time, compulsator development work has proceeded only at CEM-UT. The compulsator is a particularly attractive tactical EM gun power supply since it offers a single component providing the connection between the continuous turbine output and the railgun terminals. Energy storage between shots, power conversion, and conditioning are all accomplished within the compulsator. The need for the opening switch required by the HPG-charged-inductor power supply is eliminated and system efficiencies of around 40% (rotor kinetic energy to projectile kinetic energy) are possible.

Table II lists compulsators built, designed, or presently being designed at CEM-UT. The last column in Table II shows the compulsator which has been proposed for the tactical Armor/Anti-Armor program. It uses fiber-reinforced epoxy-matrix rotor and stator construction for increased energy density and special pulse-shaping techniques for improved effectiveness. Details of the tactical compulsator design are provided in the tactical compulsator proposal, a copy of which is included as Appendix D of this document.

Table III shows the proposed schedule for the development of compulsator-driven EM guns and their integration into demonstration EM gun weapon systems for the proposed program. The proposed program is based upon the philosophy that a laboratory based single-shot railgun should always be operating one generation ahead of the
## TABLE 2. CEM-UT COMPULSATORS

<table>
<thead>
<tr>
<th>STATUS</th>
<th>LLNL PROOF OF PRINCIPLE</th>
<th>LLNL ARFC</th>
<th>LLNL NOVA</th>
<th>DARPA/ARDC EM GUN</th>
<th>AIR-CORE COMPULSATOR (SDI)</th>
<th>AIR-CORE COMPULSATOR TACTICAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy per pulse (MJ)</td>
<td>0.15</td>
<td>0.04</td>
<td>8.5 MJ</td>
<td>0.45</td>
<td>56</td>
<td>21</td>
</tr>
<tr>
<td>Peak Voltage (kV)</td>
<td>6</td>
<td>3</td>
<td>17.8</td>
<td>2.5</td>
<td>25</td>
<td>12</td>
</tr>
<tr>
<td>Peak Current (MA)</td>
<td>0.06</td>
<td>0.026</td>
<td>0.75</td>
<td>0.8</td>
<td>2.4</td>
<td>4.4</td>
</tr>
<tr>
<td>Pulse Rate (Hz)</td>
<td>180**</td>
<td>180**</td>
<td>180**</td>
<td>60 - 240</td>
<td>65.5</td>
<td>1-160</td>
</tr>
<tr>
<td>Size (Dia. x Len.) (m)</td>
<td>0.90 x 1.5</td>
<td>0.4 x 0.5</td>
<td>1.5 x 2.6</td>
<td>1.1 x 1.5</td>
<td>3 X 4.5</td>
<td>1.36 x 1.5</td>
</tr>
<tr>
<td>Weight (tonnes)</td>
<td>7.7</td>
<td>0.5</td>
<td>36</td>
<td>10</td>
<td>70</td>
<td>5</td>
</tr>
</tbody>
</table>

* Not operational
** Not reprated
TABLE 3. COMPENSATED PULSED ALTERNATOR SCHEDULE

---|---|---|---|---|---
**Single-shot 9-MJ Launcher**
- Design and Build
- Test
- Project Development

**9-MJ Autoloader/Launcher**
- Concept
- DES
- Fabricate
- Integrate and Test

**Single-shot 15-MJ Launcher**
- Design
- Fabricate
- Install
- Test
- Project Development

**15 MJ Autoloader/Launcher**
- Concept
- Design and Integrate
- Details and Transfer
- Fabricate
- Integrate and Test

**9-MJ Three-Shot Compulsator**
- DES
- DES
- Fabrication
- Assembly
- Integrate and Test
- Fabricate

**15-MJ Compulsator**
- Design and Integrate
- Fabricate
- Integrate and Test

**9-MJ Prime Power**
- Procure
- Fabricate
- Integrate and Test

**9-MJ Vehicle and Fire Control**
- Concept
- Detail
- Fabricate
- Integrate and Test
- Select
- Design and Integrate

**15-MJ Prime Power**
- Conceptual
- Design and Integrate
- Reo & Del.
- Procure
- Fabricate
- Integrate and Test
field-based repetitive fire gun. This is essential to allow for development of rail
gun materials and structure, repetitive power supply requirements, and lethal pro-
jectiles. It is anticipated that an HPG-powered EM gun system could be developed on
a similar schedule. A crucial issue if any of these EM gun technologies are to be
developed in a university laboratory is the transfer of the technology to industry
in order that weapons system design, integration, full-scale engineering demonstra-
tion and production may proceed in the most efficient manner. After due con-
sideration we believe this issue of technology transfer can be most effectively
handled in different ways for the various components.

Homopolar generator technology and advanced concepts presently exist in indus-
try (specifically Westinghouse and General Electric Corp. as well as Parker Kinetic
Designs which is the CEM-UT Licensee) and if encouraged to mature will ultimately
provide multiple commercial sources of the technology desirable to the sponsors.

The railgun/autoloader technology is anticipated to be sufficiently straight-
forward once it is developed, that transfer can be accomplished by transfer of
drawings, reports, specifications, and possibly a seminar or short course. Also,
because there are several tactical and strategic EM gun programs, multiple commer-
cial sources of railgun technology should evolve naturally. Primary reasons for
including railgun development in the proposed CEM-UT program are the proven talent
for innovation in CEM-UT, the present availability of suitable power supplies for
developing and testing full-scale full-energy single shot prototypes, the sen-
sitivity of the power supply design to specific railgun parameters, and the desira-
bility of having single source responsibility for the EM gun system on this fast
track development program.

Transfer of compulsator technology to commercial vendors is a much more difficult task due to the absence of multiple development sources, the fact that it is based upon sophisticated, multi-disciplinary technology developed at CEM-UT over the last decade and the fact that manufacture of the electrical and mechanical componentry of the device must be tightly integrated. This last point means that not only must sophisticated design and analysis techniques be transferred, but specialized manufacturing technology and machining as well. A variety of technology transfer arrangements have been considered, including [1] having engineers from several companies working on the compulsator design and development team at CEM-UT; [2] a central technology transfer agent acting as liaison between CEM-UT and interested companies; and [3] teaming with a single company during the compulsator development program. There is concern that the first option would interfere with the open, cooperative, innovative, interactive exchange of ideas that characterizes CEM-UT programs because of competitive pressure on individual company representatives. Past experience has shown this to be the case. The critical element in the second option is of course the Technology Transfer Agent. Since this agent would need to have substantial expertise in the relevant technologies, it is not clear that it would be in the agent's best interest to be excluded from either development or commercialization of the technology, nor is it clear that this would be in the sponsor's long term interest.

CEM-UT has discussed the compulsator technology transfer issue with Parker Kinetic Designs (PKD), one company with whom CEM-UT has already had a successful
technology transfer experience. An interesting point that evolved during these discussions is that substantial manufacturing technology and specialized equipment will be required to build these air-core compulsators, and this in itself represents a potential commercial product. PKD has expressed a strong interest in working with CEM-UT on the tactical compulsator development program. One potential arrangement is that CEM-UT and PKD would team, sharing the design and fabrication duties of the prototype machines including the development of the specialized manufacturing equipment. PKD would then be in a position to license the manufacturing technology and manufacture and sell the specialized machinery to other companies as well as possibly manufacturing the compulsators themselves. CEM-UT is confident that this arrangement would ensure a successful development program as well as the availability of the necessary manufacturing equipment and technology to interested companies, but stands ready to discuss alternate approaches at the sponsor's request.
Integrated Vehicles

In the cramped confines of an armored tactical vehicle, the prospect of an electric vehicle drive system is quite attractive. Torque and speed control can be handled electrically or electromagnetically rather than mechanically with much greater freedom in component location and power train routing. The use of multiple redundant drive motors and ring-fed buswork (fig. 1) can substantially increase the reliability and reduce the vulnerability of the vehicle propulsion system. When these advantages are combined with the necessity of having an on-board electrical generator capable of converting the entire turbine output for powering an EM gun, the attractiveness of an electric vehicle drive becomes even greater.

Although it is appropriate that primary responsibility for the proposed integrated vehicles task be given to one or more vehicle designers or integrators, CEM-UT proposes to be involved in the investigation of electric vehicle drives since they may impose substantial requirements upon the EM gun system power supply and the design of the drive system could benefit from the electromechanical technology resident at CEM-UT. CEM-UT's unique design and fabrication capabilities could be valuable in prototyping and testing candidate vehicle drive systems.
Figure 1. Electric Vehicle Drive System
Competitive Evaluation Activity

The competitive evaluation activity (CEA) is the heart of the proposed track Armor/Anti-Armor development program. It must be recognized by the community as having premier technical expertise in the relevant disciplines and yet be viewed as user-friendly and non-threatening with respect to competition in the commercial sector. It must be capable of providing competent, unbiased review of programs and projects as well as design, execution, and evaluation of tests for both sponsors and contractors.

Assembling the required talent and expertise without potential conflicts of interest is non-trivial and the use of a university laboratory as an "honest broker" may well be attractive. The University of Texas has a strong commitment to supporting DoD research programs and proposes to offer its services in establishing, staffing, and operating the CEA facilities. Requirements for the CEA are perceived to include the following:

1) Full capability gun range for testing weapons and armor
2) Laboratory capability for testing and evaluation of devices and components (weapons and armor)
3) Contracting authority for the program
4) Design and execution of tests
5) Analysis and evaluation of test results
6) Documentation, reporting, briefings, and technical seminars for participants

Although The University of Texas (UT) does not have an existing gun range, it does possess a large isolated parcel of land near Odessa, Texas which would
be suitable for developing a range. The UT Permian Basin Campus at Midland/Odessa could provide office and laboratory support for the gun range.

The large, new, well-equipped Center for Electromechanics laboratory at the Balcones Research Center in Austin, Texas can provide facilities for testing and evaluation of components and devices. This laboratory has 30 MW (85 MW by 1989) of continuous electrical power available as well as a 60-MJ, 9-MA pulsed homopolar generator power supply which will be operational in May 1986, diagnostic and fabrication facilities, heavy-lift capability and room on the site for expansion of the facility. As a result of other activity in the kinetic energy weapons portions of this program, the CEM-UT labs will also be equipped with a full scale single shot EM gun range useful for impact testing and projectile development. The CEM-UT capability is complemented by several other UT resources in Austin including the Applied Research Laboratory with TOP SECRET classification on the same site, a new Cray XMP-24 supercomputer on the same site, as well as the Center for Materials Science and Engineering and the Texas Institute for Computational Mechanics on the Austin academic campus.

Although UT does not presently have contracting authority, it is willing to pursue the development of such capability. In the meantime, other options listed below are being investigated. Much of the expertise necessary for design and execution of tests and analysis and evaluation of test results is resident at UT, but the formation of a team to ensure representation of all crucial disciplines is being explored. Furthermore it is felt that the availability of such a complete team would ensure the validity of the tests and the absence of
conflict of interest because the overlapping expertise would mean that a team member would not participate when a project he was involved in was under test. The multiplicity of team members would also ease the burden of transferring program requirements and test results to the community.

The time allotted for white-paper generation does not allow for the formalization of teaming agreements, but CEM-UT has held discussions with the companies and individuals listed below in an effort to establish a team capable of providing all necessary expertise to support the program without potential conflict of interest. Given an indication of interest by the sponsor, UT intends to proceed to negotiate a teaming arrangement with each of the following entities:

<table>
<thead>
<tr>
<th>Companies</th>
<th>Contact Individual</th>
<th>Relevant Expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southwest Research Institute</td>
<td>Dr. Charles Anderson</td>
<td>Experience with gun ranges, impact diagnostics, penetration mechanics, limited hydro-code modeling, government approved contracting office.</td>
</tr>
<tr>
<td></td>
<td>Mr. Alex Wenzel</td>
<td></td>
</tr>
<tr>
<td>Stanford Research Institute</td>
<td>Dr. Don Shockey</td>
<td>Hypervelocity impact modeling and diagnostics, shock physics experiments</td>
</tr>
<tr>
<td></td>
<td>Dr. Abrahamson</td>
<td></td>
</tr>
<tr>
<td>Systems Planning Corp.</td>
<td>Mr. Don Shaw</td>
<td>Washington-based DARPA, Army, DoD liaison, conference and briefing organization classified report generation and distribution, security &quot;tank&quot;</td>
</tr>
<tr>
<td>General Research Corp.</td>
<td>Dr. Wm. Isbell</td>
<td>Hypervelocity impact experience, hypervelocity gun and range design, projectile design and modeling experience, weapon systems analysis</td>
</tr>
<tr>
<td></td>
<td>Mr. Alex Charters</td>
<td></td>
</tr>
<tr>
<td>Organization</td>
<td>Individual</td>
<td>Area of Expertise</td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>------------------</td>
<td>-----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Oak Ridge National Laboratory</td>
<td>Dr. Dave Bartine</td>
<td>Materials and failure analysis</td>
</tr>
<tr>
<td>Parker Kinetic Designs</td>
<td>Mr. Robert Parker, Jr.</td>
<td>Existing engineering, fabrication repair and service facility at Odessa, TX.</td>
</tr>
<tr>
<td></td>
<td>Mr. A. E. Prince</td>
<td></td>
</tr>
<tr>
<td>California Research &amp; Technology</td>
<td>Mr. Dennis Orphal</td>
<td>High velocity k.e. projectile design, projectile target interactions, design and execution of tests, 3-D hydrocode modeling, behind target lethality, advanced shaped charge design and analysis.</td>
</tr>
<tr>
<td>Aeronautical Research Associates of Princeton</td>
<td>Dr. Coleman Donaldson</td>
<td>Advanced armor design, composite armors.</td>
</tr>
<tr>
<td>University of Dayton Research Institute</td>
<td>Dr. Stephen Bless</td>
<td>Failure analysis, dynamic behavior of ceramics.</td>
</tr>
</tbody>
</table>

CEM-UT stands ready to discuss inclusion of other relevant expertise on the proposed team and wishes to confirm its commitment to the proposed project by offering our services and cooperation in any manner attractive to the sponsor consistent with our charter.
ESTIMATED COSTS
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Kinetic Energy Weapons</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single Shot Launchers Using BHPG/GEDI Power Supply</td>
<td>2</td>
<td>2</td>
<td>0.5</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>- 9 MJ Projectile K.E. *</td>
<td>2</td>
<td>2</td>
<td>0.5</td>
<td>--</td>
<td>--</td>
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<td>- Compulsator, P.S.</td>
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<td>- Autoloader/Launcher</td>
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<td>1.5</td>
<td>0.5</td>
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<tr>
<td>- Prime Power (4000 HP Gas Turbine) &amp; Coupling</td>
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<td>0.2</td>
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<td>- Vehicle Integration &amp; Fire Control **</td>
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<td>0.2</td>
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<td>2.1</td>
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* CEM to interface with projectile development contractor
** CEM to interface with projectile & fire control system contractor
*** CEM to interface with prime power contractor
**** Not yet sufficiently defined to cost
APPENDICES

A - CEM FACILITIES DESCRIPTION
B - CEM CONTRACT EXPERIENCE
C - IED HPG PROPOSAL
D - TACTICAL COMPULSATOR PROPOSAL
APPENDIX A

CEM/CES FACILITIES AND CAPABILITIES

Experimental Systems

- Homopolar Generators. 60-MJ modular system of six 10-MJ drum-type units. Various series-parallel combinations yield terminal voltage to 600-V; peak current to 9.0 MA; peak output power to 540-MW. Others include: 10-MJ disc-type, 6.2-MJ compact, 5.0-MJ HPG System Tester, and 3.0-MJ high voltage (superconducting field coil).

- Compulsators. DARPA/ARDC device - 1-MJ per pulse, 60-Hz firing rate, burst rated. Also active rotary flux compressor, 100-kJ per pulse, 60 Hz, burst rated.

- Energy Storage Inductors. 6 µH, 1 MA, cryogenic coaxial and 10 µH, 500 kA, cryogenic Brooks coil.

- Capacitive Energy Stores. Twelve modular stores at 60 kJ each, 10 kV, 1 MA total peak output current.

Electromagnetic Launchers

1. Coaxial, high-vacuum plasma accelerators; 1.0 and 5.0 meter long.

2. Square-bore distributed feed projectile launchers; 1 and 3 meter long.

3. Square bore, medium vacuum powder sprayer.


5. One and two meter, 1.25 cm square bore railguns rated for 1-3 gm projectiles.

Instrumentation and Control

1. RFI/EMI shield room with filtered, uninterruptible power
2. Fast event recording (48 channels)
3. Digital oscilloscope (56 channels)
4. Twelve control computers
5. 40-MB local data storage
6. 1-GB central data storage
7. Automatic data reduction/plotting
8. Hard copy oscillosgraphs (72 channels)
9. Magnetic tape storage (56 channels)
Analytical and Modeling Capabilities

1. Steady state and transient, non-linear, two and three dimensional magnetic field code capability including force and stress computation, eddy current generation, and thermal effects.
2. Performance modeling and design capabilities for electromagnetic accelerators and pulsed power systems including homopolar generators, compulsators, inductive energy stores, and opening switches.

Utilities

30-MW electric (85-MW by 1989), .25-MW compressed air, 4.2-MW chilled water, 2.1-MW hydraulic at 6,000 psi; 600-kW steam, 400-kW emergency power, bulk LN₂ storage with distributed boil-off.

Special Test Facilities

1. Controlled environment sliding contact system.
2. Tribology laboratory.
3. Rotating machinery laboratory.
4. High voltage laboratory.
5. Explosives test facility.

In-House Services

1. Chemical and metallurgical labs.
2. Electronics shop.
3. Precision machining and balancing.
4. Computational and data storage mainframe computers.
5. Publication production.

Special Features

1. 50-, 25-, 6-, and 3-ton bridge cranes, interconnecting.
2. Six-m diameter x 6-m deep covered floodable test pit.
3. 450 acre site allows for future expansion.
4. Low impedance, fault-rated grounding system.
5. Extensive fire prevention/safety systems.

Net Square Footage

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<th>Square Footage</th>
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<tr>
<td>Office and Administration</td>
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<td>Shops</td>
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<td>Low Laboratories</td>
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<td>High Laboratories</td>
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# APPENDIX B

## CEM-UT Related Experience

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<th>No.</th>
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<th>Contract Amount</th>
<th>Project Description</th>
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<tr>
<td>2.</td>
<td>Naval Research Laboratory</td>
<td>9/1/79 to 11/30/79</td>
<td>N00041-79-C-0921</td>
<td>$9,975</td>
<td>Investigation of a Homopolar-Generator Power Supply for Energy-Store Applications</td>
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<td>Department of Energy</td>
<td>2/1/79 to 10/31/80</td>
<td>DE-AS05-77ET52029</td>
<td>$300,000</td>
<td>Special Research-Support Agreement Concerning the Storage of Energy for Special Applications</td>
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<td>4.</td>
<td>Sandia Laboratories</td>
<td>3/1/79 to 3/31/80</td>
<td>13-4157</td>
<td>$136,044</td>
<td>Development of a Rotating Machine that can Deliver 700 Amperes to a Low-Impedance Load</td>
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<td>5.</td>
<td>Naval Surface Weapons Center</td>
<td>9/20/79 to 11/19/79</td>
<td>N60921-78-C-A249</td>
<td>$142,081</td>
<td>Design, Fabrication and Test of a Second-Generation Compensated Pulsed Alternator (Compulsator)</td>
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<td>National Science Foundation</td>
<td>3/15/80 to 2/28/82</td>
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<td>Study of Homopolar-Generator Pulse-Power Parameters for Application to Special Projects</td>
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<td>8.</td>
<td>Harry Diamond Laboratories</td>
<td>3/15/80 to 1/14/81</td>
<td>N60921-80-C-A033</td>
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<td>Preliminary-Engineering Design of a Compulsator or Brushless-Rotary Flux Compressor for CAMELOT</td>
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<td>10.</td>
<td>Jet Propulsion Laboratory</td>
<td>2/15/80 to 8/31/80</td>
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<td>Study of the Applicability of Inertial-Energy Storage Systems to Future-Space Missions</td>
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<td>Naval Surface Weapons Cntr.</td>
<td>6/9/81 to 12/31/81</td>
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<td>Development of Compulsator-Based Technology for the Production of Fast Pulses</td>
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<td>Lawrence Livermore Natl. Lab.</td>
<td>10/1/81 to 12/31/82</td>
<td>8030909</td>
<td>$ 78,502</td>
<td>Continued Testing and Evaluation of the Prototype Compulsator and Evaluation of Advanced Concepts</td>
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<td>National Science Foundation</td>
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<td>The Study of Resistance (Joule) Heating Using Pulse-Current Discharges from an HPG</td>
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<td>Continued Development of the Compulsator and Rotary-Flux Compressors for Pulse Power</td>
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<td>Design, Fabrication and Testing of a Phase I Technology Demonstrator for EMP Applications</td>
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<td>Sandia Laboratories</td>
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<td>26-4642</td>
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<td>The Investigation of Prototype Energy Stores for Application to Particle-Beam Accelerators</td>
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<td>Sandia Laboratories</td>
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<td>Continuation of the Study of Resistance (Joule) Heating Using Pulse-Current HPG Discharges</td>
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<td>NASA-Lewis Laboratory</td>
<td>10/1/82 to 9/30/83</td>
<td>NAG3-303</td>
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<td>Investigation of Energy Stores and Associated Switches for Earth-to-Space Rail-Launcher Systems</td>
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<td>ANCCOM/DARPA</td>
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<td>Design and Development of a Compensated-Pulsed Alternator for Rapid-Fire EMP Guns</td>
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## CEM-UT Related Experience

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<td>Development of an Ultrahigh-Speed Electromagnetic Accelerator Driven by a Capacitor-Bank Power Supply</td>
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