SMALL BUSINESS INNOVATION RESEARCH

ABSTRACTS OF PHASE I AWARDS

1994

MASTER

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PREFACE

The SBIR program enables DOE to obtain effective, innovative solutions to important problems through the private sector, which has a commercial incentive to pursue the resulting technology and bring it to the marketplace. The growing number of awardees, many of them started in business in response to SBIR solicitations, is becoming a significant resource for the solution of high risk, high technology problems for the Department. As detailed below, this publication describes the technical efforts for SBIR Phase I awards in 1994. It is intended for the educated layman, and may be of particular interest to potential investors who wish to get in on the ground floor of exciting opportunities.

The Federal SBIR Program

This program, now completing its twelfth year, was established in compliance with the Small Business Innovation Development Act of 1982, Public Law (PL) 97-219. The program was extended in October 1992 until the year 2000 by the Small Business Research and Development Enhancement Act of 1992, PL 102-564. Eleven Federal agencies have SBIR programs - those with extramural research and development (R&D) budgets of over \$100 million. The agencies were required to set aside 1.5% of those budgets in Fiscal Year (FY) 1994 to fund SBIR projects. (This amounted to about \$53 million in FY 1994 for the Department of Energy.) Each agency solicits proposals from small science- and technology-based US firms (with 500 employees or less) and makes awards competitively. SBIR research explores innovative concepts in important technological and scientific areas that can lead to valuable new technology and products. It supports innovative R&D and encourages conversion of that R&D into commercial applications of economic benefit to the Nation.

As prescribed in the legislation, the program is designed for implementation in three phases, with Phase I determining, insofar as possible, the scientific or technical merit and feasibility of ideas proposed for investigation. The period of performance in this initial phase is about six months, and the awards were limited to \$75,000 in FY 1993. Phase II is the principal research or R&D effort, and the awards were as high as \$600,000 in FY 1994 for work to be performed in a period of up to two years. Phase III is the commercial application of the research or R&D effort by the small businesses using non-Federal funding or, alternatively, it may involve follow-on non-SBIR Federal contracts for products or services desired by the Government. The program continues to strengthen the role that small, innovative firms play in meeting the Nation's research and development needs and in commercialization of ideas developed through federally funded R&D.

Phase I Awards for FY 1994

Contained in this booklet are abstracts of the Phase I awards made in FY 1994 under the DOE SBIR program. The 212 Phase I projects described here were selected in a highly competitive process from a total of 2,276 grant applications received in response to the 1994 DOE annual SBIR Solicitation. The selections for awards were made on scientific and technical merit, as judged against the specific criteria listed in the Solicitation. Conclusions were reached on the basis of detailed reports returned by reviewers drawn from DOE laboratories, universities, private industry, and government. (Any discrepancies noted in prior DOE releases naming the firms selected for awards are due either to the firm changing its name after the award selection or to the firm not proceeding to a signed grant.) It is expected that between one-third and one-half of the Phase I projects will be continued into Phase II.

The work described in the abstracts is novel, high-risk research, but the benefits will also be potentially high if the objectives are met. Brief comments on the potential applications, as described by the awardee, are given after each abstract. Individuals and organizations, including venture capital and larger industrial firms, with an interest in the research described in any of the abstracts are encouraged to contact the appropriate small business directly.

The DOE SBIR Program

DOE's FY 1994 annual Solicitation contained 43 technical topics in the areas of basic energy sciences, health and environmental research, high energy and nuclear physics, magnetic fusion energy, energy efficiency and renewable energy, fossil energy, nuclear energy, environmental management, nonproliferation and national security, and environment, safety, and health. There is keen competition because awards are made solely on the basis of scientific and technical merit, regardless of the technical topic.

As a measure of the program's success, eleven DOE SBIR projects have received R&D-100 Awards from Research and Development Magazine, which selects the 100 most significant technical products each year. In addition, five DOE awardees were chosen among the 500 fastest-growing American private companies, in the December 1991 issue of Inc. Magazine, based on their growth in sales. Also, from the first six cycles of awards (Phase II projects completed between 1986 and 1991), DOE SBIR winners have already received approximately \$260 million in Phase III funding, which is about 60% larger than the SBIR support they were given. This number is expected to grow significantly in the next few years.

The DOE SBIR program has the unique feature of providing for an optional early submission and rapid evaluation of Phase II applications, so that Phase II can be started without a gap in funding. A funding gap between Phases I and II can cause serious cash flow problems for small firms and is most difficult for businesses that are either new or very small. In the first year of Phase II awards (1984), a system was devised and implemented that allowed Phase I awardees who felt they were ready to submit their Phase II applications before their Phase I grants ended, to do so. For each of the eleven years in which Phase II awards have been made, such grantees who were chosen for Phase II funding were able to begin their projects without an interruption in funding. Since 1984, about 40 per cent of the Phase II awardees have had continuous funding between Phases I and II.

Because so many small companies lack the business skills necessary for rapid commercialization of their technologies, DOE has instituted a special training project, supported by non-SBIR funds. For the past five years, successful Phase II awardees have been given individual assistance in developing a business plan and in preparing sound and concise visual materials describing a business opportunity that could be presented to potential sponsors. The culmination of the project was a series of presentations by the SBIR awardees to the sponsors, which included representatives from large corporations and venture capital firms. As a result of participation in the 1991 project, the SBIR companies have already received more than \$14 million for commercialization of their SBIR research, with a projected royalty stream from option agreements of an additional \$24 million over the next three to five years. About 43% of the firms that completed the project have received further funding for their work. Sources of capital that wish to consider participation in future programs should contact Dr. Robert Berger, U.S. Department of Energy SBIR Program, ER-16, Washington, D.C. 20585, (telephone 301-903-3054).

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ENGINEERING ADVANCES FOR PHOTOVOLTAIC SYSTEMS

1

A Trimode Power Processor to Optimize Photovoltaic, Battery, and Diesel-Generator Sources for Economic Stand-Alone Power Plants--Abacus Controls, Inc., 80 Readington Road, Somerville, NJ 08876; (908) 526-6010
Mr. George O'Sullivan, Principal Investigator
Mr. George O'Sullivan, Business Official
DOE Grant No. DE-FG05-94ER81689
Amount: \$71,673

A hybrid power plant, consisting of a diesel generator, a battery for energy storage, a photovoltaic array or other renewable energy source, and an inverter/battery charger, will be economically feasible in the near future both within the United States and throughout the developing world where rural areas are starving for quality power. At present diesel generators run continuously; the new hybrid power plants will transfer power sources between the diesel generator and the inverter at least daily. The planned Phase I research methodically approaches the control of the inverter so that the transfer of power is a smooth process. An adaptive controller for the inverter/battery charger will measure and store the characteristics of a diesel generator in the field and adjust the transfer of power by operating the inverter in parallel with the diesel generator for a few seconds at each power transfer. The success of Phase I will be demonstrated with computer simulations that predict proper operation both in the steady state and during all power transfers.

Anticipated Results/Potential Commercial Applications as described by the awardee: The unit under investigation will provide a low cost solution for the field installation of hybrid power plants. In Phase II, a family of products spanning the power range from 50 to 250 kW will be available for prototype and small production runs. In Phase III, under company sponsorship, production tooling and value engineering will be added to the hybrid power plant to generate marketplace attractions in technology and price.

2

High Speed Sheet Growth of Thin Silicon Films--AstroPower, Inc., Solar Park, Newark, DE 19716; (302) 366-0400
Mr. Jeffrey E. Cotter, Principal Investigator
Mr. Thomas J. Stiner, Business Official
DOE Grant No. DE-FG05-94ER81713
Amount: \$75,000

A novel silicon deposition process capable of depositing high quality thin-film silicon layers on low cost supporting substrates will be investigated in Phase I. The substrate will include a reflector for light trapping. The planned deposition process will allow the formation of silicon layers 20 to 30 microns thick, optimizing the performance of crystalline silicon as a solar cell material. This new method of depositing thin silicon layers is based on an extension of existing well developed metallurgical processes. The objective of this project will be to develop the deposition process to produce 20 to 30 micron thick layers of silicon continuously. The advantages of such a process will include (1) high deposition rates (up to 100 times higher than conventional chemical vapor deposition), (2) continuous production, (3) high purity, and (4) low cost. As-deposited films will be evaluated for efficiency potential.

Anticipated Results/Potential Commercial Applications as described by the awardee: The commercial market for photovoltaics is presently limited by the cost of single crystal silicon solar cells. The planned work will advance the alternative, low cost solar cell by reducing the thickness and increasing the generation rate per unit area of the present polycrystalline silicon technology. A low-cost solar cell will have a wide market base in utility-scale photovoltaic power generation, as well as a smaller market for remote power applications.

Low Cost, High Purity Silicon by Alkaline Glycolic Digestion of Silica--AstroPower, Inc.,
 Solar Park, Newark, DE 19716; (302) 366-0400
 Mr. James B. McNeely, Principal Investigator
 Mr. Thomas J. Stiner, Business Official
 DOE Grant No. DE-FG05-94ER81712
 Amount: \$75,000

The solar cell application of crystalline silicon thin-film photovoltaic (PV) technologies is currently limited by the high cost of the silicon raw material. This is a result of the carbothermal reduction metallurgical process used to create the semiconductor-grade silicon from silica. There is a novel alternative organosilicon chemistry, based on alkaline glycolic digestion of silica, that does not involve the energy-intensive, costly carbothermal reduction. The Phase I project investigates the feasibility of this chemistry to create a high purity silicon raw material by identifying appropriate nucleophiles to effect a one- or two-step reduction of the glycolic digestion product, and by identifying purification operations on precursor intermediates. This phase concludes with a feasibility and economics study for a pilot-plant facility. The cost of silicon solar photovoltaic cells is largely affected by the cost of the silicon raw material. If the silicon raw material can be reduced from its current level of \$10 to \$15 per kilogram (based on scrap silicon fall-out from the electronics industry) to \$1 to \$2 per kilogram, a \$3 per peak watt solar cell would accordingly drop in cost to less than \$1 per peak watt. As the crystalline silicon solar cell industry grows into the 10's of megawatts, the demand will exceed the supply available from the electronics industry, and the price for the silicon raw material will increase substantially. Furthermore, as the PV industry reaches 1 gigawatt by the year 2000, it will not be able to obtain pure silicon fall-out from the electronics industry, whose total use of silicon raw material was equivalent to only 120 megawatts in 1992. This new and innovative supply of low-cost, high-quality silicon can meet the growth and demand of the crystalline silicon solar cell industry.

Anticipated Results/Potential Commercial Applications as described by the awardee: The high purity silicon material produced by the successful implementation of this process at a lower cost and at a quality that is equivalent to semiconductor-grade

silicon, could be available immediately to reduce significantly the cost of silicon semiconductor devices and crystalline silicon solar cells. This program could contribute significantly to attaining sunlight generated electricity at 5 to 6 cents per kWh and can remove the major silicon raw material obstacle to reaching 1 gigawatt capacity by the year 2000.

A Resonant Converter for Photovoltaic Systems--Electronic Power Conditioning, Inc., 1895 Northwest Ninth Street, Suite A, Corvallis, OR 97330; (503) 753-7220
 Dr. Hian K. Lauw, Principal Investigator
 Mr. Dallas A. Marckx, Business Official
 DOE Grant No. DE-FG03-94ER81746
 Amount: \$74,725

All photovoltaic (PV) systems require power electronics to convert variable voltage DC from the PV panels to usable, regulated power with high quality. At high ratings, AC is generally required. Conventional converters have several problems, including high cost, excessive harmonics, excessive losses, safety issues, poor power factor, vulnerability of the power switches, audible noise, and electromagnetic interference (EMI) in violation of FCC standards. An innovative resonant converter known as the unipolar series resonant converter (USRC) will make significant improvements in each area. The USRC uses thyristors with zero voltage and current switching, minimizing losses and cost. It produces sinusoidal voltage within IEEE 519 standards, eliminating filters and associated energy losses and cost. The USRC can step up voltage without a transformer. Versions of the USRC are operating, but adaptation to PV applications is required. This project will develop a four-wire version with a grounded neutral leg that permits the grounding of both the PV system and load without isolation transformers. In Phase I, a 3 kw version will be assembled and tested in the laboratory. In addition, the cost and performance of a 100 kw module will be projected. In Phase II, the 100 kw module could be demonstrated in the field. The 100 kw module could be installed in parallel with other similar modules in both grid-connected and standalone PV systems. The wide conversion functionality of the USRC technology makes it a

likely candidate for hybrid energy systems. A cost of less than \$100/kw is attainable for the system.

Anticipated Results/Potential Commercial Applications as described by the awardee: The result will be proof of feasibility in terms of cost and performance of the proposed resonant converter. Given its higher efficiency, low cost, and other favorable characteristics, the 100 kw module might become the converter of choice for most PV systems between 10 kw and 500 kw. Other applications include adjustable-speed drives, uninterruptible power supplies, variable-speed generation systems using wind and engine prime movers, battery chargers, and frequency changers.

5

A Photovoltaic Wire Grid Design and Process--
Energy Conversion Devices, Inc., 1675 West Maple Road, Troy, MI 48084; (810) 280-1900
Mr. Timothy J. Bernard, Principal Investigator
Mrs. Nancy M. Bacon, Business Official
DOE Grant No. DE-FG02-94ER81754
Amount: \$75,000

The current manufacturing and pilot operations utilize module assembly processes that have relatively high labor and material costs. This project addresses the cost and performance issues of processing the grids and bus bars used in amorphous silicon alloy thin film photovoltaic modules. Specifically, Phase I will address the problems of the silver paste-based current collection grid system, which compromises the reliability and adds to the cost of the amorphous silicon photovoltaic modules. Thin solid copper wires will be used as a combined grid/bus bar system wherein the wires serve the dual purpose of collecting the current from the top conductor as well as carrying it away from the active area of the cell. This new gridding process will result in cheaper photovoltaic modules that use significantly less expensive materials and have increased efficiencies regardless of the size of the module. The modules will also have improved electrical isolation as a result of the new grid system. Overall, this process improvement will enhance the performance of existing module manufacturing and pilot facilities, and increase the reliability and decrease the cost per peak watt of its modules.

Anticipated Results/Potential Commercial Applications as described by the awardee: Higher collection efficiency, lower manufacturing costs, and improved electrical isolation and reliability of photovoltaic modules over present current collection grids should be realized. This would advance photovoltaic product, process, and manufacturing technology, reduce the cost of modules and expand commercial market applications, all of which will benefit the U.S. in creation of jobs, industrial growth, and a cleaner environment, while contributing to national security by reducing the need for importation of oil.

6

Monolithic Integration of Thin Film Photovoltaics on Insulated Metal Substrates--
Energy Photovoltaics, Inc., 276 Bakers Basin Road, Lawrenceville, NJ 08648; (609) 587-3000
Dr. Alan E. Delahoy, Principal Investigator
Mr. David A. Jackson, Business Official
DOE Grant No. DE-FG05-94ER81755
Amount: \$74,924

Thin film semiconductors offer the best opportunity for cost reduction of photovoltaics. Glass is commonly used as a substrate, but breakage remains a problem. This Phase I project will demonstrate the technical feasibility of preparing monolithically integrated, thin film photovoltaic (PV) cells on insulated metal substrates. The key requirement is development of a low cost metal/insulator combination that is compatible with the PV technology. The insulating layer must exhibit good adhesion and be free of pinholes. Anodized aluminum sheet and glass-coated (porcelainized) steel have been identified as promising choices. Insulated substrates will be prepared by low temperature anodization of aluminum (Al) under appropriate conditions to form thick oxides (which will then be sealed), and by formulation of alkali aluminoborosilicate glass frits followed by bonding to low carbon steel sheet at 850°C. The coatings will be tested for adequate dielectric properties, breakdown voltage in excess of 1500 V, and ion motion. Alkali-free frits will also be evaluated. Thin film, monolithically interconnected structures will be fabricated in the configurations copper indium selenide (CIS) on porcelainized steel and amorphous silicon on anodized Al. During CIS formation, the substrate will be exposed to selenium

and to temperatures up to 550°C. The resulting devices will be analyzed by a variety of techniques for integrity of the insulator, adhesion, impurities, deleterious chemical reactions, and solar conversion efficiency. The above operations will be iterated and optimized with the goal of forming working prototype devices.

Anticipated Results/Potential Commercial Applications as described by the awardee: Successful development of sheet-metal based, monolithically interconnected, thin film photovoltaics would allow the large scale manufacture of building-integrated PV products such as roofing materials, sidings, and facades, and PV shells for electric vehicles. These multi-functional products are installed to perform conventional functions such as weather protection, but additionally generate electricity. The economic barrier to PV use is thereby reduced.

7

A Novel Interconnect Scheme for Photovoltaic Modules--Evergreen Solar Company, 107 York Terrace, Brookline, MA 02146; (617) 625-5322
Dr. Jack I. Hanoka, Principal Investigator
Mr. Richard G. Chleboski, Business Official
DOE Grant No. DE-FG02-94ER81763
Amount: \$75,000

A novel approach to the interconnection of photovoltaic cells is proposed. It utilizes cutting-edge technologies from the hybrid circuit, ceramics, and polymer fields adapted for photovoltaic processing. The entire concept has been made possible as a result of recent advances in state-of-the-art solar cell processing. This new interconnect method contacts only the rear face of the solar cell and is solder-free. This means that it lends itself to virtually continuous, high speed, low cost manufacturing, and in addition, avoids any environmental issues connected with the use of solder. Given the somewhat unique solar cell configuration, the key technical issues to be addressed in Phase I are the reduction of the metallization fingers' series resistance and maintenance of a high shunt resistance between the front and rear contacts. A detailed survey of commercially available materials in the areas of thick film pastes and high dielectric strength, low cost polymer sheet materials will be a part of this study.

Anticipated Results/Potential Commercial Applications as described by the awardee: At present, module manufacturing, of which interconnection is a significant portion, represents approximately half the cost of producing a photovoltaic panel. Because of its simplicity and high throughput capabilities, this process has the potential to significantly reduce labor, material, utility, and capital costs. Combined, these would result in an overall reduction in interconnection costs of 80%. When successfully deployed, this will be an important contribution toward the goal of economic generation of electricity from sunlight.

8

An Innovative Approach for Large Area Photovoltaic Material Processing--International Solar Electric Technology, Inc., 8635 Aviation Boulevard, Inglewood, CA 90301; (310) 216-4427
Dr. Bulent Basol, Principal Investigator
Dr. Bulent Basol, Business Official
DOE Grant No. DE-FG03-94ER81789
Amount: \$74,940

Semiconductors of copper indium diselenide and related compounds are important solar cell materials. Devices with over 15% solar-to-electric conversion efficiency have already been demonstrated on the polycrystalline thin films of these materials in the laboratory. The aim of this Phase I project is to develop new and innovative processing approaches that can be scaled up for the production of large area, high efficiency, photovoltaic modules. The approach involves reaction of indium-rich and copper-rich precursors to form a copper indium selenide film with the right composition and microstructure that can eventually be used to fabricate photovoltaic modules with efficiencies greater than 15%. The specific processing steps necessary for high efficiency solar cell fabrication will be determined, and plans made for the adaptation of these steps to a large area sputtering facility. Actual large area depositions would be carried out in Phase II.

Anticipated Results/Potential Commercial Applications as described by the awardee: If this research effort is successful, an industrial process that can produce high efficiency, large area thin film photovoltaic (PV) modules will be developed in Phase II. Thin film PV products have many terrestrial and

space power generation applications. The largest market for PV is the utility power generation market which requires a high efficiency product at low cost. Thin film PV technologies could respond to this need.

9

A 50 Watt DC-AC Inverter for Stand-Alone and Grid-Connected Photovoltaic Applications--

Solar Design Associates, P.O. Box 242, Harvard, MA 01451-0242; (508) 456-6855

Dr. Robert H. Wills, Principal Investigator

Mr. Steven J. Strong, Business Official

DOE Grant No. DE-FG02-94ER81862

Amount: \$75,000

For both utility-intertied and stand-alone photovoltaic (PV) systems, the DC wiring and its associated issues is always, except for the smallest of systems, a major problem. AC power transmission techniques will be used to completely eliminate DC interconnection. This will be done by incorporating a small DC-AC inverter on the back of each PV module so that the module output is standard 120 Volts, 60 Hz, AC current. AC power transmission can be used for both utility-interactive and stand-alone systems. A major advantage of these systems is compatibility - the 120 V AC bus provides a common ground for all components to interconnect. The benefits of maximum power point tracking on an individual module basis, the elimination of DC wiring, custom string combiners, blocking diodes, series string losses and the standardization offered by a common 120V AC bus voltage can outweigh the additional cost of the inverter. In Phase I of the effort, a proof-of-concept 50 Watt DC to AC inverter that is designed to mount on the back of a photovoltaic module will be developed. It will deliver 120 Volt 60 Hz AC power to the utility grid or to a local stand-alone grid. Appropriate manufacturing techniques (e.g. Application-Specific Integrated Circuits, hybrid circuits, monolithic and "smart power" approaches) will be examined, estimates of inverter size and the cost and efficiency for various scales of production will be prepared, and the feasibility of incorporating storage elements with the inverter on the back of the PV module to make truly modular stand-alone PV power systems will be studied.

Anticipated Results/Potential Commercial Applications as described by the awardee: This device could bring photovoltaics to the "appliance level", both for utility-interactive and for larger-scale stand-alone systems. In fact, this concept blurs the boundary between the two, as stand-alone systems effectively gain their own mini-AC grid. The main commercial market should be utility-interactive power systems, followed by support of diesel power grids in remote areas, with smaller stand-alone systems still being a significant market. The emergency power/disaster relief market could also be well served by this product.

10

Low Cost Solar Cell Leads for Use in Photovoltaic Modules--Solar Engineering Applications Corporation, P.O. Box 62246, Sunnyvale, CA 94088; (408) 986-9231

Mr. Neil Kaminar, Principal Investigator

Mr. Neil Kaminar, Business Official

DOE Grant No. DE-FG03-94ER81863

Amount: \$75,000

The copper/solder/metallization/silicon layers used to bond electrical leads to solar cells have vastly different thermal expansion rates. This causes severe stresses when continuous solder joints are used. This problem has been solved with a special lead design that uses a multitude of fingers soldered to the cells. The purpose of this project is to develop a more cost-effective lead/cell design. Two technical approaches will be investigated, to be used singularly or together. The first approach is to add a strain relief feature to a continuous lead. The second approach is to add a solder resist pattern so that continuous leads are only bonded to the cell in spots. Finite element stress analysis will be used in Phase I to investigate different designs, and proof-of-concept samples of the most promising candidates will be manufactured and subjected to environmental testing. Phase II will introduce the most successful design into the production line.

Anticipated Results/Potential Commercial Applications as described by the awardee: This project could have far reaching applications in the photovoltaic industry. If successful, the technique can be applied to other concentrators and to one-sun modules. Given modest volume, the introduction of

a more cost-effective lead/cell design, and other planned improvements, could enable the grid to be sold for under \$1.10 per installed AC Watt.

11

Very Low-Cost/High-Efficiency Thin-Film Silicon Photovoltaic Technology--Spire Corporation, One Patriots Park, Bedford, MA 01730-2396; (617) 275-6000

Dr. Anton C. Greenwald, Principal Investigator
Mr. Patrick N. McDonnell, Business Official
DOE Grant No. DE-FG02-94ER81867
Amount: \$74,992

The goal of this project is to achieve a cost reduction on the order of 50% in thin-film photovoltaic (PV) technology by developing a high-efficiency chemical vapor deposition (CVD) silicon cell utilizing a low-cost substrate. In Phase I a surface relief structure will be formed on a glass substrate by making a negative replica of a reusable texture-etched silicon surface. A thin silicon film will be deposited on this textured substrate by CVD from silane and then recrystallized by rapid thermal annealing. The artificial surface relief will induce a preferred orientation of the regrown crystallites (graphoepitaxy) so that the film has a nearly single crystal, or at least large-grained (≥ 1 mm), structure. In Phase II, a cell structure with all contacts on the back surface will be fabricated, the textured glass substrate becoming the light-trapping front cover of the cell. Although highly innovative, this approach is at an acceptably low level of risk because it is based upon the synthesis of five previously demonstrated technologies: graphoepitaxy, scanned recrystallization, interdigitated back contact cell structures, light trapping, and high lifetime CVD silicon.

Anticipated Results/Potential Commercial Applications as described by the awardee: The capability of depositing high quality, thin-film silicon cell structures directly from a source gas onto low cost substrates will obviate the long-standing economic barriers to large scale PV power generation. Its impact upon the commercial, environmental, and strategic well-being of the Nation has been stated repeatedly and in great detail by the various Federal PV initiatives.

12

Development of a Low Cost High Concentration Photovoltaic Dense Array Module for Use with Reflective Concentrators--SunPower Corporation, 435 Indio Way, Sunnyvale, CA 94086; (408) 991-0900

Dr. Pierre Verlinden, Principal Investigator
Dr. Richard Swanson, Business Official
DOE Grant No. DE-FG03-94ER81872
Amount: \$74,314

A one kilowatt test-bed photovoltaic reflective dish system with 13.6 percent overall efficiency has been demonstrated. The dish was operated for two months, at which time one of the receiver modules developed a crack in its substrate and began leaking coolant. Phase I will design and fabricate a second-generation dense-array module and test it on a one kilowatt test-bed concentrator. The new module will use an alumina substrate, rather than the silicon substrate of the first-generation design, along with a new substrate-to-module-housing seal based on o-rings, rather than the adhesives of the first-generation design. The same innovative, integral heat exchanger will be employed. The module will be subjected to qualification testing and operated for an extended period to demonstrate reliability. By incorporating new 26 percent efficient cells into a new dense-array module design, it is hoped to demonstrate the feasibility of high-performance, reliable, cost-effective photovoltaic dish systems with an overall efficiency of over 16 percent.

Anticipated Results/Potential Commercial Applications as described by the awardee: Successful demonstration of a cost-effective, high-concentration dense-array module is the remaining technical hurdle for commercialization of reflective photovoltaic concentrator systems. The primary early application of reflective-dish photovoltaic systems will be for distributed-generation grid support in areas with high air conditioning peak loads, and for remote photovoltaic diesel hybrid power systems for military bases, resorts, and islands currently operating on diesel generators.

FUEL CELLS FOR TRANSPORTATION

13

Improved Activated Carbon for Hydrogen Storage--Arcanum Corporation, P.O. Box 1482, Ann Arbor, MI 48106; (313) 665-4421

Mr. John A. Getsoian, Principal Investigator

Mr. Helmut F. Stern, Business Official

DOE Grant No. DE-FG02-94ER81710

Amount: \$73,821

Amoco process activated carbons have been found to have high storage capacity for alternate fuel vehicle energy sources such as hydrogen and methane. Nearly all of the gas these carbons can store is adsorbed in microporous regions where pore diameters are less than 40 Å. However, the micropores only account for somewhat more than half of the total pore volume in these materials. The balance of the pore volume comprises of large pores which do not store low molecular weight gases efficiently. Analysis of the process reaction chemistry and material balance indicate that novel modifications to the existing synthesis technique may result in an activated carbon product with a much higher proportion of its total pore volume in the microporous range. Such a material should have substantially higher gas storage capacities than currently available materials and could provide substantial improvements in the cost and feasibility of hydrogen or methane fuel vehicles. Phase I will construct a suitable batch reaction system for the synthesis of Amoco carbon and execute a plan designed to test the effects of reductions in water feed to the reaction system and the effects of feed mesophase concentration on micropore yield. Additional dehydration of the caustic in the reactor will be attempted prior to feeding the carbon substrate. Testing will determine whether it is feasible to design equipment to the fairly narrow requirements of the reaction that will have enough evaporation capability to achieve significant additional concentration of 87% potassium hydroxide upstream of the carbon feed point.

Anticipated Results/Potential Commercial Applications as described by the awardee: The anticipated result of this approach is a demonstration of the feasibility of producing activated

carbon adsorbents with higher volumetric gas storage capacities. An attendant benefit of increased volumetric capacity yield will be a reduction in capital cost of production because the equipment for this process is sized for the bulk volume of the material going through it, while the value of the product inheres in the storage capacity within that volume. Thus the same equipment can produce more total volume storage capacity. Since commercial potential of this material is highly sensitive to its cost/performance ratio, the success of the proposed approach will increase the commercial viability of the product and of technologies such as hydrogen or methane fueled vehicles in which it may be used.

14

Non-Precious Metal Catalysts for Proton Exchange Membrane Fuel Cells by Ion Beam Synthesis--ElectroChem, Inc., 400 West Cummings Park, Woburn, MA 01801; (617) 932-3383

Mr. Calvin L. Bushnell, Principal Investigator

Dr. Radha Jalan, Business Official

DOE Grant No. DE-FG02-94ER81744

Amount: \$75,000

One of the challenges facing the commercialization of proton exchange membrane (PEM) fuel cell technology involves the reduction of cost, specifically that of the electrocatalyst. The search continues for non-noble metal catalysts which are lower in cost and exhibit equivalent or better performance. PEM fuel cells for transportation power sources have additional benefits if they have a capability to operate efficiently on fuels derived from methanol. This requires that the anodes have a tolerance to impurities without poisoning the catalyst. In previous work carbon materials which were surface activated with nitrogen were found to have significant catalytic activity for phosphoric acid cathodes. Furthermore, transition metals were deposited on carbon supports as well. The procedure was based on ion implantation. This Phase I project will prepare both anode and cathode catalysts, evaluate them in PEM cells for their catalytic activity and their tolerance to contamination contained in methanol and methanol reformat, and

compare them to platinum catalysts. Higher cathode catalytic activity will be accomplished by the use of an electron cyclotron resonance ion beam source to create higher charge state ions to increase the reaction rate in preparing the catalyst surface. Anode catalysts will be prepared by novel and proprietary methods to catalyze carbon supports with transition metals.

Anticipated Results/Potential Commercial Applications as described by the awardee: At the end of Phase I, the potential catalytic activity of anode and cathode catalysts prepared by ion-beam synthesis should have been demonstrated. If successful, this approach paves the way to fabricate low cost and impurity tolerant PEM fuel cells for use in transportation.

15

Contamination-Tolerant Anodes for Polymer Electrolyte Membrane Fuel Cells--ICET, Inc., 916 Pleasant Street, Unit 12, Norwood, MA 02062; (617) 769-6064

Dr. Shantha Sarangapani, Principal Investigator
Mr. Srinivasan Sarangapani, Business Official
DOE Grant No. DE-FG02-94ER81779
Amount: \$75,000

Polymer Electrolyte Membrane (PEM) fuel cells have several advantages over conventional electrolyte fuel cells. Their high power densities make them prime candidates for electric vehicles, in conjunction with a methanol reformer. However, the impurities from the methanol reformat affect the performance of the platinum catalysts, causing reduction in power densities. This project aims to develop certain macrocyclic promoters for countering the poisoning effect of the adsorbed residues from the impurities present in the hydrogen stream. Several catalyst systems will be screened in half cells and selected catalysts will be tested in a PEM fuel cell. During Phase II these catalysts will be developed towards maximum power densities.

Anticipated Results/Potential Commercial Applications as described by the awardee: Phase I is expected to result in the identification of certain enhanced catalysts for use with reformat in PEM fuel cells. A good poison-resistant catalyst will make

the cost of electric vehicle power sources affordable for consumer use.

16

Contamination-Tolerant Anodes for Proton Exchange Membrane Fuel Cells--Lynntech, Inc., 7610 Eastmark Drive, Suite 105, College Station, TX 77840; (409) 693-0017

Dr. Oliver J. Murphy, Principal Investigator
Dr. G. Duncan Hitchens, Business Official
DOE Grant No. DE-FG05-94ER81800
Amount: \$75,000

There is a renewed interest in fuel cells as primary power sources for electric vehicles. The acidic proton exchange membrane fuel cell operates at a maximum temperature of 95°C and, at present, relies on the use of platinum-based electrocatalysts. For acid fuel cells operating at temperatures below 130°C, hydrogen is the most active common fuel that can be used. However, to be of practical use for power generation, a fuel cell must be capable of using an available fuel, such as methanol or natural gas. For transportation applications, it has been proposed that the hydrogen required for proton exchange membrane fuel cells will be produced by the steam reforming of methanol. However, the steam reforming of methanol results in the production of low levels of carbon monoxide. The presence of carbon monoxide and trace contaminants, such as formaldehyde, acetaldehyde, formic acid, and acetic acid in the hydrogen fuel gas stream severely degrades the performance of proton exchange membrane fuel cells, since carbon monoxide acts as a poison to platinum electrodes operating in the range of potentials, 0-0.5 V (normal hydrogen electrode), at temperatures less than 130°C in acidic electrolytes. In addition to selective catalytic oxidation of carbon monoxide in the reformer output, a number of other methods have been considered. An alternative approach to avoid the degradation in performance of proton exchange membrane fuel cells by carbon monoxide and other small organic molecule contaminants, is to develop contamination-tolerant anodes for use in this fuel cell system. Thus, the goal of this project is to overcome the poisoning problems encountered in using platinum metal-based electrocatalysts in proton exchange membrane fuel cells supplied with hydrogen fuel derived from steam-reformed methanol. Phase I will investigate the feasibility of using novel metal oxide anodes

which are not sensitive to the presence of small organic molecule contaminants or other impurities for the oxidation of hydrogen gas. It is only recently that metal oxide electrodes have been used for hydrogen evolution as well as hydrogen oxidation in acidic and alkaline solutions. Tafel slopes of 40 mV/decade of current density and exchange current densities approximately one order of magnitude lower than platinum have been reported for these materials.

Anticipated Results/Potential Commercial Applications as described by the awardee: The anticipated result of this approach, if the project is successful, is the development of novel contamination-tolerant anodes for proton exchange membrane fuel cells. These will allow the use of methanol reformat as a fuel feed gas for low-temperature fuel cells such as the proton exchange membrane system. Proton exchange membrane fuel cells have considerable value as electric vehicle power sources. Other applications for proton exchange membrane fuel cells include portable power sources for communications and news gathering equipment, portable medical instrumentation used by rescue teams, and applications that require emergency or back-up power sources or pulse power.

17

Metal Carbide Nanoclusters for Polymer Electrolyte Membrane Fuel Cells--TDA Research, Inc., 12345 West 52nd Avenue, Wheat Ridge, CO 80033; (303) 940-2301

Dr. Ronald L. Cook, Principal Investigator

Mr. Michael E. Karpuk, Business Official

DOE Grant No. DE-FG03-94ER81882

Amount: \$75,000

Polymer electrolyte membrane (PEM) fuel cells are promising candidates for localized power generation and transportation applications because of simplicity of design, low weight, and low temperature operation. Although hydrogen based PEM fuel cells are considerably more advanced, direct methanol PEM fuel cells have better long term commercialization potential because of their high energy densities and ease of storing methanol, a liquid fuel. Distribution and marketing of methanol fuels could be accomplished by the existing infrastructure for gasoline. Unfortunately, the promise of direct

methanol fuel cells is unrealized because of the lack of stable, high performance, low cost electrocatalytic materials for methanol oxidation. Only very highly loaded (and therefore very expensive) platinum/ruthenium electrocatalysts have shown high and sustained activity for methanol oxidation under fuel cell conditions. This project will prepare and evaluate a recently discovered new class of materials as electrocatalysts for methanol oxidation in a direct methanol PEM fuel cell. These newly developed materials are molecular metal carbide clusters that may exhibit unique catalytic and electrocatalytic properties. In Phase I a series of metal carbide cluster compositions will be prepared and evaluated for their activity as methanol oxidation electrocatalysts. Phase II research will be directed towards optimization of electrode composition, catalyst loading, and cell designs using these materials for direct methanol PEM fuel cell power sources.

Anticipated Results/Potential Commercial Applications as described by the awardee: Novel molecular metal carbide clusters prepared in this project may exhibit activity for the methanol oxidation reaction. Low cost, stable, high activity methanol oxidation catalysts for PEM fuel cells would allow the use of direct methanol cells across both civilian and military sectors of the economy.

IMPROVED FORMABILITY OF MAGNESIUM ALLOYS FOR AUTOMOTIVE APPLICATIONS

18

A Superplastic Oxide Dispersion Strengthened Magnesium Alloy for Automotive Applications--
Chesapeake Composites Corporation, 239 Old Churchman's Road, New Castle, DE 19720; (302) 324-9110

Mr. Eric M. Klier, Principal Investigator
Dr. Alexander Brown, Business Official
DOE Grant No. DE-FG05-94ER81728
Amount: \$74,350

Reduction of automobile weight is an important approach to reducing fuel consumption. Magnesium alloys would offer the potential for significant weight reductions if they were more readily formed and their stiffness could be increased. High strain rate superplastic forming offers a cost effective route for the production of automotive components. However, to be superplastic, magnesium alloys must possess a unique set of microstructural features. Magnesium alloy systems which possess such microstructures are not readily available. Recently a new class of low

cost, corrosion resistant, oxide dispersion strengthened (ODS) magnesium alloys have been synthesized by a novel liquid metal process. These materials meet the microstructural requirements for superplasticity and based on previous research, should be superplastic at strain rates consistent with conventional forming processes (10^0 to $10^1/s$). These ODS alloys also offer a 45 to 190% increase in stiffness compared to conventional magnesium alloys. During Phase I, ODS magnesium alloys will be produced, extruded, and tensile tested at elevated temperatures and a variety of strain rates to determine if they are indeed superplastic.

Anticipated Results/Potential Commercial Applications as described by the awardee: If ODS magnesium is superplastic at high strain rates, it represents a generic approach to the production of low cost, high performance magnesium alloy systems which can be economically formed into automotive components. These components would reduce the weight of automobiles, improving their fuel efficiency and thereby reducing our dependence on foreign oil.

INDUSTRIALIZED PASSIVE SOLAR BUILDINGS

19

Modular/Transportable Classroom Structures--
Aspen Systems, Inc., 184 Cedar Hill Street, Marlborough, MA 01752; (508) 481-5058
Dr. Roy Richard, Principal Investigator
Dr. Kang Lee, Business Official
DOE Grant No. DE-FG02-94ER81711
Amount: \$75,000

This project will design and develop a new breed of energy efficient modular/transportable classrooms that will incorporate daylighting, passive solar techniques, natural ventilation, and solar water heating. The product will be based on innovative construction techniques and technologies resulting in an energy efficient and physically and psychologically

healthful environment for the students and teachers. The changing demographics throughout the country cause many school systems to experience significant fluctuations in student population resulting in an immediate, and possibly only temporary, need for more classroom space. Each year in the United States, tens of thousands of transportable classroom modules are used as a means of rapidly providing the required space at a reasonable cost. Significant energy savings can be realized in these structures through the incorporation of state of the art materials and solar energy utilization. The Phase I effort will focus on the development of solar lighting, heating, and ventilation, and their integration into a modular structure. Emphasis will be placed on ergonomics and economics to assure a user friendly, affordable classroom. The Phase II program will

pursue the detailed design, fabrication, and performance testing of a full scale prototype.

Anticipated Results/Potential Commercial Applications as described by the awardee: In addition to the tens of thousands of modular classrooms that are used each year, many other uses are possible, such as for offices, day care facilities, laboratories, cafeterias, dormitories, and stores, all of which exist in both the private commercial sector and within the various branches of government.

20

Design and Evaluation of Energy Efficient Modular Classroom Structures--Modern Building Systems, Inc., P.O. Box 9493, Porter Road, Aumsville, OR 97325; (503) 749-4949
Mr. James Stanard, Principal Investigator
Mr. Donald Rasmussen, Business Official
DOE Grant No. DE-FG03-94ER81814
Amount: \$75,000

The objective of Phase I of this project is to develop innovations that will enable modular classroom builders to improve the energy performance of their classroom modules while adding only reasonable first costs to the project. To achieve this objective detailed computer simulations will be performed on the various innovations to gauge their improvements over baseline statistics gathered from existing modular classrooms in a variety of climatic regions of the United States. These innovations will center around modifications to existing thinking and technology in ventilation, ventilation pre-heating, and daylighting as well as wise use of high and low peak load energy usage data through automatic control systems that will not only be user friendly but help to eliminate user control error, thus saving energy. These design modifications will improve not only the energy performance of the classrooms but improve or enhance the thermal comfort, ease of transportation, flexibility of use, and the psychological well being of the students and teachers.

Anticipated Results/Potential Commercial Applications as described by the awardee: The impact of these types of innovation on the market in the energy-conscious Pacific Northwest could be significant. They could become a voluntary requirement of most, if not all, school districts in the

region. That could translate into 200 to 300 classrooms per year. At an average value of \$30,000 per classroom, the market potential even in this small area is very exciting. In the Nation as a whole these innovations could be beneficial to thousands of school districts through many manufacturers. Specific groups that might be expected to use the projected results include public and private school districts across the country, including elementary and secondary schools, community colleges, universities, and churches. The results of this study will provide data that would lead to a Phase II project and actually place prototype buildings for testing at various schools in many climate regions.

21

An Integrated Anamorphic Daylighting Roof Aperture (ADRA) System Based on Non-Imaging Optical Components--Physical Optics Corporation, 2545 West 237th Street, Suite B, Torrance, CA 90505; (310) 320-3088
Dr. Tomasz Jansson, Principal Investigator
Ms. Patty Shaw, Business Official
DOE Grant No. DE-FG03-94ER81828
Amount: \$74,990

There are three emerging technologies that can significantly advance state-of-the-art daylighting systems for interior illumination. This project will develop a non-tracking, integrated Anamorphic Daylighting Roof Aperture (ADRA) system that will incorporate each of these technologies. This system will be based on the integration of new non-imaging optical components and low-loss plastic fibers for delivering solar light to building interiors. The first new component will be an anamorphic non-imaging light collector which transforms elliptical beams into circular beams and achieves the theoretical limit of Liouville's concentration principle. Only anamorphic concentrators can effectively collect solar light for different latitudinal and azimuthal solar angles without mechanical tracking. Additionally, non-imaging collectors will also be used as beam expanders in the building's interior. They will be combined with unique holographic non-Lambertian beam-shaping diffusers. These diffusers can improve lighting efficiency by distributing light to only a selected limited solid angle, which is optimum for office illumination. These diffusers do not exhibit

any significant back scattering losses and can be mass replicated using low cost embossing techniques. Phase I will combine these components with low-loss plastic fibers to produce efficient compact daylighting systems, which can be readily incorporated into roof structures. The resulting ADRA system will be modular and versatile which will make it ideally suited for integration with electrical and heating, ventilating, and air conditioning systems and electronic networks.

Anticipated Results/Potential Commercial Applications as described by the awardee: The successful completion of this project will produce inexpensive durable daylighting systems for new and existing buildings. They can provide significant energy savings and have a positive environmental impact through the use of solar energy.

22

Design of a Family of Advanced Prototype Passive-Solar Modular Classrooms--Steven Winter Associates, Inc., 50 Washington Street, Norwalk, CT 06854; (203) 852-0110
Mr. Steven Winter, Principal Investigator
Ms. Marie Costello, Business Official
DOE Grant No. DE-FG05-94ER81870
Amount: \$75,000

This Phase I research effort will integrate three separate disciplines to develop high-performance

passive-solar modular classrooms: architectural design, passive solar systems, and modular production technology. Historically, no program or project has applied such integration to educational facilities. Even though the necessary skills have been available, no research sponsor has allocated the necessary resources. This project will use in-house specialists to develop prototype designs, supported by technical committees of the Modular Building Institute and the Passive Solar Industries Council. Completed designs will then be subjected to rigorous energy performance and life-cycle cost analyses to verify cost/benefit. Final designs for a family of passive-solar modular classrooms will be prepared, suitable for subsequent construction, testing and commercialization of prototypes.

Anticipated Results/Potential Commercial Applications as described by the awardee: If the project is successful a system of innovative passive-solar modular classrooms will have been designed, analyzed as to effectiveness, and tested to prove performance. Details of the design and its performance will be made available to members of the Modular Building Institute, who are responsible for modular classroom construction nationwide, and design/production consortia will be formed for widespread commercialization. This will positively impact the annual production of an estimated 30,000 modular classrooms, and is expected to lead to the purchase of many more modular classrooms once their potential customers are made aware of energy performance, comfort, and life-cycle cost benefits.

WIND TURBINES: EFFICIENCY IMPROVEMENT USING ADVANCED POWER ELECTRONICS

23

A Look-Ahead Adaptive Control System (LACS) for Wind Turbine Generators--AeroVironment, Inc., 222 East Huntington Drive, Monrovia, CA 91016; (818) 357-9983
Dr. Paul B. MacCready, Principal Investigator
Mr. Thomas Zambrano, Business Official
DOE Grant No. DE-FG03-94ER81700
Amount: \$74,999

Existing control systems for pitch-controlled wind turbines stabilize rotor power by adjusting blade pitch in response to over-or-under power conditions in a feedback loop. The pitch control mechanism lags behind the rotor power variations that are being controlled. The time lag causes power output fluctuations that necessitate over-dimensioning of rotor, transmission, and generators to obtain a satisfactory service life. Also, it causes frequent start-stop cycles when the wind speed fluctuates about the cut-in point. An innovative look-ahead

acoustic wind speed and turbulence sensor will be used to eliminate the time lag. The adaptive control system will pitch the rotor blades in anticipation of a gust (feed-forward), rather than after its arrival. The resultant more stable rotor power removes the need for down rating of the equipment leading to greater energy capture and fewer start-stop cycles. Feed-forward control is inherently stable. This feature is crucial, because it drastically reduces the difficulty of implementing expert systems for adaptive control. The adaptive controller itself, is designed to influence blade pitch without becoming part of the stability-sensitive pitch control feed-back loop. Thus, the Look-Ahead Adaptive Control System (LACS) can be retrofitted to existing machines, without affecting their existing control systems. Phase I is dedicated to proof of concept testing. Control algorithms are developed using computer simulation. They are tested by using an existing acoustic wind sensor facing upwind from the foot of the tower of the wind turbine used for testing. In Phase II, the system will be developed into a compact unit for commercial installation on the hub of wind turbines.

Anticipated Results/Potential Commercial Applications as described by the awardee: The wind speed and turbulence data provided by the look-ahead acoustic sensor permit the adaptive controller to minimize reduced energy capture by the wind turbine caused by lack of tuning. The reduction in rotor power fluctuations allows operation of the generator at increased power or, at unchanged power rating, it will extend component fatigue life. The number of start-stop cycles will be reduced.

24

A Resonant Converter for Universal Wind Application--Electronic Power Conditioning, Inc., 1895 Northwest Ninth Street, Suite A, Corvallis, OR 97330; (503) 753-7220

Dr. Hian K. Lauw, Principal Investigator
Mr. Dallas A. Marckx, Business Official
DOE Grant No. DE-FG03-94ER81747
Amount: \$72,289

With a variable-speed generation (VSG) system, a wind turbine can turn at any speed and still produce constant frequency and voltage power which is compatible with the grid. The primary benefits of

VSG include increased energy production, increased power capacity, soft-starts, control of torque perturbations, dynamic electrical braking, and power factor control. All of the modern techniques for implementing VSG rely on a power electronic converter or conditioner. Conventional converters have several well-known problems: high cost, excessive power losses, harmonics losses and winding damage in the generator, poor power factor, and audible noise. An innovative resonant converter known as the unipolar series resonant converter (USRC) would make dramatic improvements in each problem area. The USRC uses thyristors with zero voltage and current switching, thus minimizing losses and cost. It is also inherently bi-directional and produces sinusoidal voltage within IEEE 519 standards at both the input and output, thus eliminating supplemental filters, audible noise, and winding deterioration. In Phase I, a 400 kW USRC that can be used widely in many types of variable-speed wind turbines will be designed and assessed as to feasibility (performance and cost). In Phase II, the design will be assembled and installed in the field in an advanced wind turbine.

Anticipated Results/Potential Commercial Applications as described by the awardee: The planned resonant converter attacks directly the problems with existing converters used in wind systems today. When implemented with a flexible, universal control interface, it can be widely applied in almost any wind turbine system to enable variable speed operation. It will be marketed widely to the wind industry. This technology will also be used in adjustable-speed drives, photovoltaic systems, fuel cell systems, battery storage systems, frequency changers, and actuators.

25

A Versatile, Technically Accessible Wind Turbine Controller--Electronic Power Conditioning, Inc., 1895 Northwest Ninth Street, Suite A, Corvallis, OR 97330; (503) 753-7220

Dr. Hian K. Lauw, Principal Investigator
Mr. Dallas A. Marckx, Business Official
DOE Grant No. DE-FG03-94ER81745
Amount: \$74,861

Two broad deficiencies in controls are apparent in the wind industry. The first is that a significant

number of advanced wind turbine designers simply do not have controls that are adequate to compete in the wind industry. This is understandable since the strengths of most wind turbine designers fall in the area of machines, structures, and aerodynamics. The second is that most wind turbine controllers do not use the most advanced control techniques, such as rule-based algorithms, expert systems, and fuzzy logic, nor do they contain the most up-to-date digital control components, such as applied specific integrated circuits, digital signal processors, and field programmable gate arrays. Specific problems include (1) a cost several times more than it should be, (2) insufficient speed and complexity for current and future requirements, (3) doubtful reliability, (4) awkward interfaces with a system control and data acquisition (SCADA) system, and (5) the inability of the turbine supplier to support his product adequately by being able to understand and adapt the controller. This project will develop a reliable, responsive, low cost, fully integrated control system for advanced wind turbines that can be understood and modified by a single control engineer with generally available skills. The control system will contain the most advanced control concepts and the most advanced digital control hardware. In Phase I, the first step will be taken toward this objective by designing the hardware and software structure of the single turbine control and a compatible SCADA system. In Phase II, these would be assembled and tested in the field on at least two operating, advanced wind turbine designs.

Anticipated Results/Potential Commercial Applications as described by the awardee: The expected result is that all wind turbine designers would have a versatile, practical, state-of-the-art controller at reasonable cost. This need would be satisfied for a significant number of identifiable designers of advanced wind turbines who are now without such a controller. Because of the open architecture and technical accessibility of the proposed controller, it might become a standard in the industry. Since the control and SCADA requirements of other energy systems, such as dispersed engine generator sets, are quite similar, the controller would be used widely outside of the wind industry.

Wind Turbine Power Electronics with Hybrid Integrated Circuits--R. Lynette and Associates, Inc., 15042 Northeast 40th Street, Suite 206, Redmond, WA 98052-5353; (206) 885-0206

Dr. T. S. Jayadev, Principal Investigator

Mr. Robert Lynette, Business Official

DOE Grant No. DE-FG03-94ER81840

Amount: \$74,863

Recent progress in hybrid power integrated circuit (IC) development can be taken advantage of in the design of new, innovative power electronic variable-speed systems for wind turbines. The continued advancement of these power ICs into larger rating and lower prices is assured because of the vast market in the adjustable AC drive business. The planned system employs these devices in a direct-drive (i.e., no gearbox) power electronics package that solves the current problems with variable-speed systems: high complexity and cost of the power devices and large power losses associated with variation of rotor speed over too high a range. A unique power electronics/generator scheme is planned in Phase I to significantly reduce the power requirements and complexity of the power electronics, resulting in reduction in capital cost.

Anticipated Results/Potential Commercial Applications as described by the awardee: This generator power electronics technology will contribute significantly to reducing the cost of energy (COE) from wind power plants. In concert with the improvements in the aerodynamic performance, the new scheme offers the potential to reduce COE below 4 c/kWh. If this cost goal is met, DOE estimates that there will be a 100-fold increase in wind power generation, with installed capacity of 120,000-160,000 MW.

ON-SITE REMEDIATION OF CONTAMINATED MEDIA

27

Removal and Recovery of Mercury from Contaminated Waters--ADA Technologies, Inc., 304 Inverness Way South, Suite 110, Englewood, CO 80112; (303) 792-5615

Dr. Daryl Roberts, Principal Investigator
Dr. Michael D. Durham, Business Official
DOE Grant No. DE-FG02-94ER81691
Amount: \$74,881

Removal of mercury from contaminated waters is a continuing need for DOE's site remediation efforts. Some surface and subsurface discharge of contaminated water is continuing from mercury lost to the environment in the past. In the future, it is anticipated that mercury-contaminated structures and equipment will be subjected to aqueous washes, and that this water will need to be treated before discharge to the environment. Activated carbon, ion exchange resins, and derivatives of algae have been proposed for this purpose, but these techniques often remove only a small portion of the mercury and generate solid or liquid wastes from which the mercury may volatilize or be leached. The Phase I research project will investigate the feasibility of removing mercury from contaminated waters at DOE remediation sites with novel, regenerable sorbent beds. This sorbent-based technology will recover the mercury, removing it completely from the biosystem, and will allow DOE sites to ensure compliance with legislated discharge limits for mercury. The proposed sorbents have a high capacity for mercury, and the estimated capital cost of the proposed technology is no more than that of activated carbon systems used for the control of organics in waste waters.

Anticipated Results/Potential Commercial Applications as described by the awardee: The technology will make mercury removal and recovery possible for contaminated waters at DOE remediation sites, for wastes being processed by the Department of Defense, and for industrially-generated contaminated waters.

28

A Continuous High-Capacity Water Treatment Process for the Recovery of Heavy Metals--Apogee Corporation, 2501 North Loop Drive, Ames, IA 50010; (515) 292-8251

Dr. Joseph J. Hanak, Principal Investigator
Dr. Joseph J. Hanak, Business Official
DOE Grant No. DE-FG02-94ER81708
Amount: \$75,000

An advanced waste-water treatment process for continuous separation of ionic species, including heavy metals, from aqueous solutions has been developed. This process shows a potential for separation of a variety of components from complex mixtures at sufficiently high capacity and low cost to be suitable for application on an industrial scale. The objectives are to provide validation and develop specific applications for the new process and to establish its competitiveness with existing processes. A demonstration of efficient separation of heavy metals from surface mine waters is planned. The approach will be to make use of a dynamic prototype device to conduct a program of demineralization tests on heavy metal contaminants such as those found in the Berkeley Pit, an inactive copper mine in Butte, Montana. Phase I will consist of a study of the dependence of the demineralization parameters on a defined matrix of independent process parameters. It is expected that substantial gains in the rate of separation, the separation ratio, energy efficiency, and low process cost will be realized.

Anticipated Results/Potential Commercial Applications as described by the awardee: Based on results to date, a successful development of the application of the new process is expected for the removal and recovery of heavy metals from waste water and the restoration of water quality to accepted standards. Future applications will include mobile and stationary high-capacity systems (1 to 10 million gallons per day, per unit) for continuous treatment of contaminated surface water generated by mining or by manufacturing industries. Revenues from the recovered metals and water are projected to exceed process costs by a substantial margin.

A Biopolymer Based Selective Barrier for the Containment of Groundwater Contaminants--

TDA Research, Inc., 12345 West 52nd Avenue, Wheat Ridge, CO 80033; (303) 940-2301

Dr. Kevin Gleason, Principal Investigator

Mr. Michael E. Karpuk, Business Official

DOE Grant No. DE-FG03-94ER81878

Amount: \$75,000

The contamination of groundwater by heavy metals, radionuclides, and organics is a serious environmental problem. In some cases it may not be possible to remove all of the material from the soil by conventional pump-and-treat techniques. In such cases, the residual material must be contained to prevent further migration. An ideal solution would be a permeable barrier that is readily installed and retains the contaminants yet allows water and innocuous ions to pass through. The objective of this project is the development of a biopolymer based permeable barrier. This system is environmentally sound and inexpensive. It can be formulated as a liquid for ease of emplacement, but once in place, it gradually hardens into a permeable solid. The resulting barrier has a high adsorption capacity for metal cations, is selective for some of the most hazardous heavy metals and radionuclides, and can also sorb anions and organics. Phase I will evaluate the sorptive capacity of the barrier material, determine formulations suitable for emplacement by conventional methods, and demonstrate the formation of a continuous barrier. During Phase I a site will be selected for a Phase II test and efforts will be focused on developing a formulation that will successfully address problems associated with that site. The projected cost and potential effectiveness of the system will be determined. Phase II, if warranted, will systematically investigate the effects of changes in composition on the properties of the barrier, including the methods for emplacement.

Anticipated Results/Potential Commercial Applications as described by the awardee: If this project is successful, the result will be a system for treatment of contaminated groundwater that is low cost and suitable to contain contaminants in groundwater at a large number of polluted sites. The system would find use by the Government and private companies in stabilizing or containing hazardous waste sites.

Heavy Metal Remediation of Soil Using Permeable Chelation Barriers--TPL, Inc., 3768 A/B Hawkins, Northeast, Albuquerque, NM 87109; (505) 344-6744

Dr. Franklin O. Kroh, Principal Investigator

Ms. Patricia Cabrera, Business Official

DOE Grant No. DE-FG03-94ER81892

Amount: \$75,000

Remediation of soil and groundwater to reduce heavy metal contaminants to background levels poses a serious challenge. Conventional methods are able to reduce contamination levels, but total remediation, defined as achievement of background levels of the metal, may not be economically feasible. A permeable chelation barrier containing silica gel modified to chelate heavy metals provides an economical method to attain complete remediation of contaminated soils. Silica gel will be modified by attachment of amine, polyamine, or polyamine polycarboxylate groups, yielding a solid material capable of binding ions of heavy metals including lead, chromium, cadmium, and uranium. The chelating gel then is contained in a permeable fabric, and placed in a trench surrounding moderately contaminated soil, where it functions with minimal maintenance, requiring only periodic monitoring of metal concentration. When metal capacity is achieved, the barrier is removed and regenerated for further use. In Phase I such chelating silica gels containing amine, polyamine, and polyamine polycarboxylate groups will be synthesized. The metal capacity of the gels will be measured, and ease of regeneration determined. Recovery of the metals will be evaluated. Use of silica gels in permeable chelation barriers will be expanded to soil remediation in Phase II activities. The benefits of this technology include total remediation of metal contaminated soils and protection of sensitive water sources without a labor-intensive intervention. In this way, partial remediation can be accomplished in a cost-effective manner resulting in reduction of hazardous metals to background levels.

Anticipated Results/Potential Commercial Applications as described by the awardee: The benefit of this project is a low-maintenance technique to reduce metal contamination levels to background levels, while protecting groundwater sources. Commercial applications of permeable chelation

barriers would be in remediation and reclamation of mine spoils, metal plating plants, and radionuclide contaminated areas.

EXPEDITED WASTE SITE CHARACTERIZATION

31

Development of Penetration Enhancement for the Cone Penetrometer Using Sonic Drilling Technology--Applied Research Associates, Inc., Box 102A, Waterman Road, South Royalton, VT 05068; (802) 763-8348

Dr. Wesley L. Bratton, Principal Investigator
Mr. Scott E. Blouin, Business Official
DOE Grant No. DE-FG02-94ER81709
Amount: \$74,830

In this project, the feasibility of combining sonic drilling and cone penetration technologies will be evaluated and a set of preliminary design drawings developed. Sonic drilling technology has recently been demonstrated at the Hanford Site, WA. The results of the demonstration proved that small diameter monitoring wells could be installed to the desired depth in a rapid manner using this technology. Production rates were nearly double those of the standard cable tool methods used, which resulted in a significant cost savings. Cone penetration technology (CPT) has had limited success in penetrating the gravel formation of the Hanford Site. At areas where the CPT has been able to penetrate, a significant cost saving has been realized. Typical costs for the CPT at Hanford are \$65/ft compared to \$800/ft for cable tool drilling. Given the number of investigation and monitoring wells required at the Hanford and other DOE sites, savings of tens of millions of dollars will be realized using the sonic-CPT method. By developing this technology, the utility of the CPT can be extended to deeper depths and more locations at both Hanford and other DOE sites. In addition, the development of larger probes and sensors will require this technology to reach the depths of current CPT sized probes. The end result of Phase I will be a set of design drawings which can be used to fabricate a prototype for evaluation in Phase II.

Anticipated Results/Potential Commercial Applications as described by the awardee: Phase I will result in preliminary design drawings of a sonic-CPT system. These drawings will be used in Phase II to fabricate and evaluate the system. Based on the results of a field demonstration, a final design will be determined, and commercial units can be developed. These units would then be available to expand the role of hazardous site investigations at the DOE sites, especially the Hanford and Savannah River Sites.

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A New Semiconductor Radiation Sensor for Expedited Waste Site Characterization--Aurora Technologies Corporation, 7408 Trade Street, San Diego, CA 92121-2410; (619) 549-4645
Dr. F. P. Doty, Principal Investigator
Dr. J. F. Butler, Business Official
DOE Grant No. DE-FG03-94ER81714
Amount: \$74,922

The overall goal is to develop low cost "smart" sensors for hard x-rays suitable for use with minimally intrusive emplacement systems such as cone penetrometers and portable instruments. The sensors will efficiently measure energy spectra up to 300keV, an important range for spectroscopic determination of the actinide radioisotopes and for x-ray fluorescence of heavy metals. The sensors will incorporate recent advances in cadmium zinc telluride (CdZnTe) detector technology, smart sensor technology, and x-ray spectral analysis techniques and electronics. Sensor capabilities will include: 1) localization of radionuclide contamination, 2) quantification by spectral analysis, and 3) analysis of soil properties and heavy metal contamination. The sensors will provide significant advantages over existing room temperature technology, including improved energy resolution, small size, low power operation, and solid state reliability and ruggedness.

Phase I will establish feasibility by analyzing preliminary detector response characteristics, and will furnish improved pulse readout electronics, methods for quantitative interpretation, and engineering parameters required to build a Phase II prototype sensor.

Anticipated Results/Potential Commercial Applications as described by the awardee: The program should result in commercially available, low cost, smart x-ray sensors useful to both the private and public sectors for environmental monitoring, nuclear safeguards, oil and mineral exploration and other applications. This new sensor technology may have significant export business potential, and provide real benefit to the nation's economy.

33

A Micromachined Chemical Analysis System for Waste Site Characterization--Berkeley Micro-Instruments, Inc., 1301 South 46th Street, Building 164, Richmond, CA 94804; (510) 231-5710
Dr. Stuart W. Wenzel, Principal Investigator
Dr. Ben J. Costello, Business Official
DOE Grant No. DE-FG03-94ER81715
Amount: \$74,351

The identification and quantification of toxic chemicals is essential for the cost-effective remediation of hazardous waste sites. The development of a chemical microinstrument is proposed for environmental analysis: a silicon chip containing multiple micromachined components that work together to attain the high selectivity and sensitivity characteristic of conventional analytical instruments. This chip will be the enabling technology for hand-held chemical analyzers that are user-friendly, inexpensive, and battery operated, yet have the power to perform the sort of chemical analysis that now requires expensive, fragile laboratory instruments. The aim in Phase I will be to design and build critical components of the micromachined chip. The circuitry and algorithms to control the individual chip elements will be designed and tested, and tests will be performed to evaluate the validity of the approach and to guide further development.

Anticipated Results/Potential Commercial Applications as described by the awardee: This technology should be broadly applicable to in situ

waste site characterization, "smart" cone penetrometers, feedback-control of waste-remediation processes, classifying waste products in known storage facilities, personal chemical-exposure monitoring, and indoor-air-quality monitoring.

34

A Personal Computer Window-Based Systematic Hazardous Waste Management Evaluator (SHOWME) for Waste Site Data Processing--Consultants for Environment System Technologies, 10 Damara Street, Irvine, CA 92714; (714) 724-9908
Dr. Sumant K. Gupta, Principal Investigator
Dr. Sumant K. Gupta, Business Official
DOE Grant No. DE-FG03-94ER81731
Amount: \$75,000

At a cost of billions of dollars, nationwide field and laboratory investigations are being performed to characterize and clean the contaminated DOE and DOD facilities and several Superfund sites. A dynamic interactive Systematic Hazardous Waste Management Evaluator (SHOWME) is planned in Phase I to (1) systematically summarize and display geologic, hydrologic, and chemical data, (2) execute statistical tools to facilitate in-field, step-wise, dynamic planning and execution of site characterization activities, and (3) quantitatively evaluate transport of chemicals. The data processing module of the software package will generate self explanatory data summaries, concise display of each monitoring station information, and three dimensional interactive visualization of the given site geo-hydrologic system and contaminations. Interface with statistical analysis tools will facilitate consideration of geologic layers, anisotropy, trends, correlation geostatistics, and site specific models. SHOWME pre- and post-processors for interface with three dimensional finite element flow and transport code will (1) simulate complex geometry of waste site geologic systems, (2) provide tools to evaluate alternative remedial measures, and (3) perform sensitivity analyses for likely benefits of proposed additional site characterization. The software package will be based on a modern window type graphical interface to maximize user friendliness. Each key dialogue box, pull-down menu, and interactive option will include instant display of instructional window and help keys. In summary, SHOWME will provide the means to systematically

process the data collected, maximize the use of available information, minimize the investigation cost by timely visual display of information, and expedite site characterization.

Anticipated Results/Potential Commercial Applications as described by the awardee: SHOWME interactive software tools will provide an easy, elegant means to process, analyze, and visualize several megabytes of site characterization information. SHOWME output will facilitate (1) systematic interpretation of geologic, hydrologic, and chemical contaminants, and (2) timely and sound decision-making for field managers, decision makers, and regulators. SHOWME code has several potential uses by federal, state, and public agencies; landfill operators; environmental consultants; regulators; and the petrochemical industry. Efficient, timely processing of information and enhanced understanding of contaminant distribution are likely to reduce site characterization costs by millions of dollars.

35

Electrocore Electrokinetic Core Sampling and Monitoring--ISOTRON Corporation, 13152 Chef Menteur Highway, New Orleans, LA 70129; (504) 254-4624

Mr. Richard A. Graves, Principal Investigator

Mr. Henry L. Lomasney, Business Official

DOE Grant No. DE-FG05-94ER81790

Amount: \$73,098

LOW-LEVEL MIXED WASTE PROCESSING

36

An Acoustic Plate Mode Aqueous Mercury Sensor--BIODE, Inc., 2 Oakwood Road, Cape Elizabeth, ME 04107; (207) 883-1492

Dr. Douglas McAllister, Principal Investigator

Dr. Douglas McAllister, Business Official

DOE Grant No. DE-FG02-94ER81717

Amount: \$74,600

There is a critical need for a fast, simple sensor for aqueous mercury in waste, surface, and ground

water. It has been found that trace metals that previously were not detected as present in soil samples can be concentrated at detectable levels. This project will tailor current electrokinetic technology to design an innovative soil sampling and monitoring method involving an in-situ sorbing of trace contaminants from the soil by concentrating them into a solid matrix under the influence of an applied potential over a limited time interval. Two design concepts are planned for both fabrication and experimentation for the electrokinetic soil sampling and monitoring apparatus. One design comprises fabricating both anode and cathode into a 1 to 1.5 inch polymeric cylinder which is capable of concentrating both anions and cations into an easily analyzable matrix. The other design has an independent anode and cathode and is capable of not only concentrating the contaminants but also of in-situ determination of the target species. Both designs also have the potential of being used for estimating ion mobility and soil retention times.

Anticipated Results/Potential Commercial Applications as described by the awardee: The technology produced by this research will allow profiling and monitoring of contaminant levels in soil even at very low concentrations. The technology will provide a safe, easily installed, low maintenance sampling system requiring low exposure of work personnel to hazardous conditions.

water. This sensor is required for the DOE remediation efforts as well as the more widespread efforts in environmental protection. Such a sensor should be able to react to nanogram per milliliter levels of mercury. The sensor is capable of direct immersion in solution and should provide continuous data on either cumulative mercury exposure or instantaneous concentration. Spectroscopic methods, such as atomic absorption, atomic emission, and atomic fluorescence provide adequate sensitivity; however, these are discrete laboratory techniques and cannot be employed for continuous monitors or

in the field. One method of detecting ppb to ppm levels of mercury in solution involves the use of novel class of piezoelectric sensors, known as the shear horizontal acoustic plate mode (SHAPM) sensor. These sensors measure the perturbation of acoustic wave, in situ, to changes in electrical and mechanical properties. They are readily operated in contact with a fluid medium and are sensitive to subnanogram quantities of mass adsorbed onto their surface. The SHAPM has the potential to rival cold vapor atomic absorption and atomic fluorescence spectroscopy techniques, while simultaneously offering in-situ, continuous monitoring. The monitor is expected to provide a measure of the mercury concentration in minutes and to be reusable many times. Phase I will demonstrate the principal of operation of the new sensor to detect nanogram per milliliter levels of mercury in solution. This effort will include the fabrication of several devices with different films which are expected to confer specificity for mercury. Responses of the sensors will then be measured over various mercury concentrations. Effects of possible interferents will also be examined. Phase II will concentrate on optimization of the most promising device which will include aspects such as durability, reusability, signal processing, and packaging.

Anticipated Results/Potential Commercial Applications as described by the awardee: This project should lead to field- and factory-based monitoring instruments for aqueous mercury which will be capable of performing discrete, in-situ measurements of mercury. Although not directly addressed, other films could be developed for the selective detection of other metal contaminants (e.g., cadmium or uranium), volatile organic compounds (VOCs) or gaseous pollutants (e.g., NO_x, SO₂, or H₂S).

37

An Off-Line-Locked Laser Diode Sensor (OLDS)--Spectral Sciences, Inc., 99 South Bedford Street, #7, Burlington, MA 01803-5169; (617) 273-4770

Dr. Jamine Lee, Principal Investigator
Dr. Fritz Bien, Business Official
DOE Grant No. DE-FG02-94ER81865
Amount: \$75,000

Secondary waste stream monitoring requires real-time/continuous measurements of hazardous gas

species. Although baseline techniques using gas filter correlation and ion-selective electrodes have been demonstrated for monitoring hydrogen chloride off-gas at a hazardous waste incinerator, none of these techniques are suitable for monitoring corrosive or reactive gases such as hydrogen fluoride. An off-line-locked laser diode sensor which will provide automatic, unattended, real-time, in-situ monitoring of selected toxic gases will be developed in Phase I. The instrument extends current laser absorption technology to the measurement of unstable gas species in harsh stack conditions. The technique provides active control of the laser emission without use of a sample molecule for reference, which can be chemically unstable and physically unsafe for the instrument operation. This will provide performance and cost advantages in the detection of a large number of toxic species, including hydrogen fluoride, hydrogen chloride, hydrogen bromide, carbon dioxide, carbon monoxide, nitrogen dioxide, hydrogen cyanide, and hydrogen sulfide at concentrations ranging from below the threshold level to well above the acute damage level.

Anticipated Results/Potential Commercial Applications as described by the awardee: The planned sensor can be used for continuous emission monitoring of hydrogen fluoride and other corrosive and reactive gas species in numerous applications. These include monitoring waste off-gas from incineration plants, petrochemical processing, and detecting accidental toxic emissions in industrial processes. Further development could lead to extensions to more complex applications, including monitoring of multiple species using a single common probe. This sensor offers significant advantages in terms of cost, size, and automation over currently available baseline techniques and commercial instruments for waste stream off-gas monitoring.

ARMS CONTROL AND NONPROLIFERATION VERIFICATION AND DETECTION TECHNOLOGY

38

Microdevices for Proliferation Detection--
Deacon Research, 2440 Embarcadero Way, Palo Alto,
CA 94303; (415) 493-6100
Dr. William Bischel, Principal Investigator
Dr. Olive Lee, Business Official
DOE Grant No. DE-FG03-94ER81736
Amount: \$75,000

There is a need in the arms control community for a compact, low cost, sensitive sensor for remote detection of the products of proliferation activities. This project is concerned with a sensor based on the microchip capillary electrophoresis (CE) and high performance liquid chromatography (HPLC) technology recently developed at Oak Ridge National Laboratory (ORNL). This potentially battery-powered sensor would be capable of inorganic ion detection in the field for arms control verification, as well as numerous other government and commercial chemical sensing applications. Development of the laser diode based light source is being pursued, and the fabrication of the separation columns has already been demonstrated at ORNL. Phase I is expected to eliminate the key remaining risk in the development of this sensor-the optical detection system. Phase I should result in the fabrication of the detection system and the measurement of the fluorescence of a test analyte. A collaborative effort with ORNL will begin to design a prototype of the integrated microchip sensor that will be fabricated and tested in Phase II.

Anticipated Results/Potential Commercial Applications as described by the awardee: The development of a miniature chemical sensor is anticipated, for use as a rugged field instrument for chemical analysis, a long-lifetime sensor for manufacturing process control, or a chemical analyzer for laboratory use.

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Human Presence Detection in Vehicles--ENSCO,
Inc., 5400 Port Royal Road, Springfield, VA
22151-2301; (703) 321-9000
Dr. Thomas A. Gamble, Principal Investigator
Dr. Norman Bush, Business Official
DOE Grant No. DE-FG05-94ER81758
Amount: \$74,998

An existing system has demonstrated, in quiet conditions, very reliable detection of humans hidden in vehicles. Seismic vibrations are the major, unavoidable limitations. Measurement of the seismic vibrations and coherent analyses will be utilized to compute and subtract the effect of the seismic interference on the vehicle motion. The Phase I effort will improve the reliability, increase the search rate, and expand the conditions under which the system can operate. Data will be collected, optimized statistical techniques will be defined for the subtraction of seismic noise interference, and the detection algorithm will be enhanced. The requirements for a field test system incorporating these enhancements will be defined.

Anticipated Results/Potential Commercial Applications as described by the awardee: The subtraction of the seismic interference should enable reliable human presence detection in vehicles at all locations. The security and effectiveness of entry/exit portals is a concern at military and classified facilities, especially rapid reaction force facilities in foreign countries. This will become more common in a world of sustained, low intensity conflict and long term peace-keeping missions. Border check points, prisons, commercial firms, and residential buildings also often require vehicle inspections for unauthorized personnel.

Reliable Intrusion Detection--ENSCO, Inc., 5400 Port Royal Road, Springfield, VA 22151-2301; (703) 321-9000

Dr. Thomas A. Gamble, Principal Investigator

Dr. Norman Bush, Business Official

DOE Grant No. DE-FG05-94ER81757

Amount: \$74,998

Reliable intrusion detection may be achieved by combining generalized potential function (GPF) neural net construction and multiple sensor data fusion. Traditionally, reliable intrusion detection can be difficult because noise levels change with time and location, and an intrusion may produce a wide range of signals or variations over the different types of sensors. Accommodating these variations is not practical using standard classification techniques. A self-organizing classification technique, such as a neural net, provides a means for learning the idiosyncrasies of a particular location and fully utilizing data from various intrusion detection sensors (seismic, acoustic, electromagnetic, temperature, pressure, etc.). Many methods of neural net construction have been developed. Most have deficiencies for intrusion detection. An impractical number of training instances may be required, or the confidence of detection may not be reliably indicated. The GPF method of neural net construction has demonstrated a superior ability to characterize complex classes and to quantify the confidence of classification. The Phase I effort will set up a testbed including a variety of sensors, and will monitor/record all sensor outputs simultaneously as simulated intrusions occur. The recorded data set will be used to train and test the GP net intrusion detection algorithmic formulation. The false alarm rate and probability of detection will be compared to those of the individual sensors, and this approach will be optimized for Phase II. In Phase II, a field test prototype system will be developed, incorporating real-time training of the GP net classifier and real-time intrusion detection. The performance of this system will be evaluated using simulated intrusions. A production system will be produced and installed during Phase III.

Anticipated Results/Potential Commercial Applications as described by the awardee: This system will provide more reliable intrusion detection for sensitive nuclear facilities. Physical security is a

major concern at many facilities other than nuclear. All military and classified facilities have to effect some sort of entry control. Many civilian activities also require intrusion detection. International borders are an important example. Many commercial and residential buildings and sites also restrict access for security reasons and could provide a large commercial market for a reliable, convenient device.

Human Presence Detection Based on Imaging Sensors and Image Processing and Analysis--

Physical Optics Corporation, 20600 Gramercy Place, Suite 103, Torrance, CA 90501; (310) 320-3088

Dr. Wayne Lian, Principal Investigator

Ms. Patty Shaw, Business Official

DOE Grant No. DE-FG03-94ER81829

Amount: \$74,976

Existing human presence detection systems suffer from high false alarm rate and limited programmability because they lack intelligent signal processing. A system based on image processing and analysis technique will address these problems. The image data is acquired by an infrared imaging sensor and a charge-coupled device (CCD) camera. Motion detection and pattern recognition are employed to detect human presence. In addition, the system incorporates an innovative signs-of-life detection technique, based on detecting micro-motions of breathing, eye blinking, and head turning. Data fusion reduces false alarm rate. The Phase I work will establish the feasibility of the proposed approach. Algorithms for motion detection and pattern recognition will be implemented in a personal computer. The effectiveness of the signs-of-life detection will be evaluated experimentally using human subjects, a CCD camera, a CCD-to-computer interface board, and a computer for signal processing. Phase I will include an estimate of the system's detection and false alarm rates. In Phase II, an operational human presence detection system will be constructed.

Anticipated Results/Potential Commercial Applications as described by the awardee: The proposed system has applications in guarding buildings, including storage spaces and warehouses. It is highly flexible and programmable, able to

communicate with a remote operator, and cost effective.

42

Security Monitoring Systems: Sensors, Communications, and Computing--Spectrum Data, Inc., P.O. Box 3100, Kent, WA 98032; (206) 824-9337

Mr. Warren Brent Chitwood, Principal Investigator
Mr. Rod Davidson, Business Official
DOE Grant No. DE-FG03-94ER81866
Amount: \$75,000

Accurate and automatic detection of human presence in order to prevent unauthorized use of high value assets is an important issue for both DOE and society in general. To date, security systems have been very expensive in terms of capital and very labor intensive to operate. In addition, the systems have been prone to false alarms, reducing confidence in the alarms generated. In this project a security monitoring system based on a unique combination of video acquisition, wireless spread spectrum communications, and morphological image processing to detect the presence of human intruders is planned. The ultimate goal is to reduce by a factor of 10 the capital costs and installation labor (compared to conventional security systems), reduce false alarms to near zero, produce the positive detection of humans with near 100% accuracy, and provide fully automated operation. Phase I investigates morphological image processing for human detection, implements the test bed detection system, and validates the system concept based on actual video. The software for image processing runs on a workstation or personal computer for the test bed. The software will be analyzed to determine the requirements for porting to low cost dedicated digital signal processing. Cost analysis will determine if the signal processing should be done in hardware, in software, at remote nodes, or at central hubs. Design alternatives will be suggested for changes in the image processing software or image files transferred to optimize cost and performance. The final report will provide test results, suggest design alternatives based on test results, and summarize the analysis of software and hardware requirements to develop a prototype for field testing.

Anticipated Results/Potential Commercial Applications as described by the awardee: The

expected result of this project is the proof of concept that human presence can be automatically detected and confirmed with a very low false alarm rate using wireless data communication systems and advanced signal processing and can be manufactured for a low cost (under \$600 a node). Controlling crime is a major issue in the United States. Currently around 9.95 billion dollars per year is spent on security systems. These monitored systems have excessive false alarm rates. With the successful completion of this system, government, business, and consumers can use a new generation of security system with near zero false alarm rate and very low installation and operating costs.

43

Detecting Human Presence Using Synchronized Omnidirectional Video and Thermal Imaging--TeleRobotics International, Inc., 7325 Oak Ridge Highway, Knoxville, TN 37931; (615) 690-5600
Mr. H. Craig Grantham, Principal Investigator
Dr. H. Lee Martin, Business Official
DOE Grant No. DE-FG05-94ER81885
Amount: \$74,900

DOE is actively pursuing innovative techniques for detecting human presence in enclosed areas. This is necessary for such circumstances as personnel safety in vaults containing special nuclear materials, intrusion detection in sensitive facilities, and even automating vehicle inspection. The key objective is to eliminate false alarms while providing positive determination when a human is present. The proposed effort eliminates false alarms by combining multiple sensors, video, and thermal signature using a patented imaging technology called Omniview, coupled with custom imaging analysis, to make a positive determination. The Omniview provides video images with pan, tilt, magnify, and rotation (P/T/M/R) performed electronically, with no moving parts. It allows viewing of large fields-of-view up to 180 degrees by correcting any lens distortion, and provides multiple images from a single camera, each with dependent P/T/M/R. Integrating a visible spectrum video signal with a thermal video signal will provide an extremely positive determination, since multiple parameters and decision criteria are available. The concept will result in a wireless, battery powered unit making it covert, portable and easy to retrofit into existing facilities. In the phase I effort, the feasibility of the human detection system

will be verified and proof-of-principle demonstrated, including dual-image transmission and verification of the performance of the basic subsystems.

Anticipated Results/Potential Commercial Applications as described by the awardee: The system being developed would have numerous applications in industrial and commercial security, as well as remote surveillance of sensitive military and nuclear facilities.

44

Seismic Detection of Individuals Hiding in a Vehicle--Utah Geophysical, Inc., P.O. Box 9344, Salt Lake City, UT 84109; (801) 272-4957

Mr. Lewis Katz, Principal Investigator

Mr. Lewis Katz, Business Official

DOE Grant No. DE-FG02-94ER81895

Amount: \$39,510

External monitoring devices for detecting humans hiding in vehicles are needed to prevent unauthorized access to restricted military areas and to prohibit illegal immigrants from entering the United States at border crossings. Several investigators have found that a seismometer, placed on a vehicle, can be used to detect an intruder's heart sounds. In

the absence of wind noise, the observed signal level of the heartbeat exceeds background noise levels by 20 db. The vehicle's suspension system appears to amplify the heart sounds while isolating noise from the ground. Previous efforts to utilize this method have been hampered by wind noise. The wind shakes the vehicle, masking the heartbeat signals. Previous investigations have also been limited to detecting only a single individual hiding in a car or truck. Unique characteristics of heart sounds have been identified that are likely to make them more apparent in the presence of noise. This Phase I project will use innovative seismic data acquisition and processing methods to detect an individual's heartbeat and thus determine if an intruder is hiding in a vehicle. The planned method can also be used if more than one person is hiding in the vehicle.

Anticipated Results/Potential Commercial Applications as described by the awardee: Information obtained in Phase I of this study will provide data needed to develop a seismic monitoring system, capable of determining if individuals are present in a vehicle, without physically searching the vehicle. This monitoring system will be of value for military security and U.S. Border Patrol agents. There are also possible applications for this system in the medical and health industries.

INTERNATIONAL ATOMIC ENERGY AGENCY SPECIAL SAFEGUARDS INSPECTIONS

45

Plutonium Assay Using Superheated Drop Technology in Support of International Atomic Energy Agency Safeguards--Apfel Enterprises, Inc., 25 Science Park, Suite 676, New Haven, CT 06511; (203) 786-5599

Mr. Jesus D. Martin, Principal Investigator

Mr. Robert E. Apfel, Business Official

DOE Grant No. DE-FG05-94ER81707

Amount: \$74,976

The end of the cold war has switched the focus from building weapons of deterrence to minimizing the chances for the use or proliferation of nuclear

weapons. Thus, arms control verification and the careful monitoring of the Nuclear Non-Proliferation Treaty are essential components of any international effort to assure safety from nuclear threats and security around the world. Success in verification and monitoring are only possible if instrumentation has adequate sensitivity for the radiation type of interest and gives an unambiguous and immediate readout. There are practical requirements as well. The instrumentation should be readily portable, should be easy-to-use, and should save the radiation fluence history for later analysis. It should complement other instrumentation designed to support the Safeguards Program of the International Atomic Energy Agency. Superheated drop (bubble)

technology (SDD) promises such characteristics and overcomes some of the limitations of gamma spectrometry and ^3He coincidence counting. Phase I consists of the research and development that will consider the feasibility of a small, microprocessor-based neutron spectrometer that will count bubble events produced by neutrons. Spectrometry will be accomplished by using SDD compositions possessing different neutron energy thresholds. This system will complement gamma spectrometry in providing immediate display of the radiation fluence and flux as well as immediate or delayed downloading of the radiation record to a compact, battery-powered personal computer. From such records, on-site inspectors should be able to make reasonable assays of the amount of plutonium present, with the possibility of differentiating between spontaneous fission neutrons and neutrons produced by α -n reactions. The entire system, which should fit in an attaché-sized case, may also find application in low-level environmental monitoring of transuranic wastes.

Anticipated Results/Potential Commercial Applications as described by the awardee: If feasibility is demonstrated, then the project will produce a compact and highly sensitive spectrometer for neutrons that will serve to alert inspectors to the presence and amount of plutonium. Such instrumentation may also have applications for short-term, low level transuranic waste monitoring and other environmental surveys of importance to DOE.

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High Energy Resolution Cadmium-Zinc-Telluride Semiconductor Radiation Detectors--
Spire Corporation, One Patriots Park, Bedford, MA
01730-2396; (617) 275-6000

Dr. Rengarajan Sudharsanan, Principal Investigator
Mr. Patrick N. McDonnell, Business Official
DOE Grant No. DE-FG02-94ER81869
Amount: \$74,955

There is a need for improved, miniaturized radiation detectors for on-site measurements of containers of nuclear material, particularly uranium and plutonium. Detectors currently available require cryogenic cooling (high-purity germanium) or lack the energy resolution necessary to verify plutonium

accurately (sodium iodide). Cadmium telluride detectors have been a promising alternative but have suffered from materials and device problems which have prevented them from realizing their potential. Phase I should demonstrate a room temperature CdZnTe p-i-n radiation detector with sensitivity and energy resolution that is superior to current CdTe detector technology. The improvement would result from an improved mobility-lifetime product and higher intrinsic resistivity for CdZnTe compared to CdTe. Additionally, the historic ohmic contact problems of CdTe would be overcome by grading the composition of the p and n contact layers to ZnTe and CdTe, respectively. The enhanced performance of this detector will be verified by measuring the gamma ray sensitivity and energy resolution of the device using high energy radionuclide sources. Detector structure will be optimized during Phase II and prototype miniaturized probes will be built for verification of nuclear materials.

Anticipated Results/Potential Commercial Applications as described by the awardee: The Phase I project should demonstrate that, with attention to issues of material quality and ohmic contacts, CdZnTe room temperature gamma ray detectors can be fabricated with sensitivity and energy resolution superior to that of competing technologies. Applications for these detectors will include portable miniaturized probes to monitor uranium and plutonium in nuclear facilities as well as gamma spectroscopy and X-ray astronomy.

INNOVATIVE FOSSIL SOLIDS AND LIQUIDS PROCESSING AND RELATED CROSSCUTTING APPLICATIONS

47

Adaptive Control of Nitrogen Oxide Reduction Processes--Advanced Fuel Research, Inc., 87 Church Street, P.O. Box 380379, East Hartford, CT 06138-0379; (203) 528-9806

Dr. Anthony Bonnano, Principal Investigator

Mrs. Sally E. Solomon, Business Official

DOE Grant No. DE-FG05-94ER81695

Amount: \$74,945

Recent legislation in the U.S. and abroad, driven primarily by environmental concerns, has led to the development of technology to reduce the levels of nitrogen oxide (NO_x) emitted from combustion facilities. Application of this technology to coal-fired power generation facilities has been particularly important because of the relatively high nitrogen concentration of typical coals (0.5 to 2%). Selective catalytic and non-catalytic reduction (SCR and SNCR) are flue gas clean-up processes that use a reducing agent (usually ammonia or urea) to convert NO_x into molecular nitrogen and water. Although these processes can often reduce NO_x concentrations by over 90%, variations in process temperatures or improper control of ammonia injection rates can lead to increased NO_x concentrations or "ammonia slip". Ammonia slip not only defeats the goal of reduced emissions (ammonia is an air toxic), but can also cause operational problems in the plant, such as corrosion, and will contribute to ash fouling. The complexity of these processes, variability in boiler load and temperature profiles, and the difficulties associated with monitoring ammonia slip all create a difficult control problem for NO_x reduction using flue gas clean-up technology. This project will employ artificial neural networks (ANNs) to adaptively model and control NO_x reduction processes using the boiler and process parameters as input and the resulting NO_x and ammonia concentrations as output. The capability of ANNs to learn from observation, together with their inherent ability to model nonlinearity, make them ideally suited to the problem of process control in complex processes. The Phase I project will concentrate on flue gas clean-up processes, although this methodology should also be applicable to modified

combustion strategies such as air staging. New ammonia monitoring technology currently under development will provide previously unavailable input data for model development.

Anticipated Results/Potential Commercial Applications as described by the awardee: The successful completion of this project would result in process control methodology for maximizing NO_x reduction capabilities while minimizing ammonia slip (or boiler inefficiency in the case of modified combustion strategies). This technology would clearly provide both economic and environmental benefits to the Nation; potential installations exist at thousands of sites in the U.S. and abroad.

48

A Molecular Dynamic Aided Advanced Diagnostic Tool for Granular Flows--Cambridge Hydrodynamics, Inc., P.O. Box 1403, Princeton, NJ 08542; (609) 683-1515

Dr. William S. Flannery, Principal Investigator

Ms. R. Karp, Business Official

DOE Grant No. DE-FG05-94ER81722

Amount: \$75,000

The ever increasing need to process large quantities of solid fuels like coal provides strong motivation to study the dynamics of flowing granular materials. Laboratory experiments are hampered by the lack of adequate diagnostic tools and means to control the flows. Field experiments are very expensive as well. Also, scale dependence implies that results of laboratory or semi-industrial scale experiments may not be relevant to large scale industrial systems. Recent algorithmic advances as well as the availability of fast superworkstations enable the use of new molecular dynamic simulations to study granular systems containing up to a million particles in practically any desired geometry and for any prescribed geometrical or dynamical properties of the particles or the boundaries. The measurement of full velocity, stress, granular temperature, concentration fields, flow rates, density profiles, and other macroscopic and microscopic properties of the flows

using simulation results is now possible. The large number of particles that can now be simulated enables the study of relatively large scale systems. In contrast, most previous particle dynamics computer codes could simulate a few thousand particles in a simple enclosure and a few hundred particles in complex flow situations. The existence of a new clustering scale in granular systems which indicates that the dynamical properties of small systems may be qualitatively different from those encountered in large systems has now been demonstrated. This renders simulations of systems containing a relatively small number of particles of limited applicability. The diagnostic simulation code to be developed in Phase I will be fast, user friendly and sufficiently versatile to handle variable geometries and particle and boundary properties.

Anticipated Results/Potential Commercial Applications as described by the awardee: The coal and fossil industry, power plants, and other industries worldwide can benefit significantly from reliable diagnostic and design methods. The design and operation of silos, bins, chutes, hoppers, and of many other systems will be improved, rendering them more efficient. Troubleshooting in such systems can be highly facilitated by the use of good diagnostic tools. Compliance with the Clean Air Act Amendments of 1990 will be easier while keeping energy prices at reasonable levels. State-of-the-art algorithmic methods and statistical mechanical techniques will be harnessed to achieve the goal of producing a user-friendly simulation tool and associated diagnostics for solid fuel flows.

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Gas Separation Membranes Based on Permselective Films of Buckminsterfullerenes-
CeraMem Corporation, 12 Clematis Avenue,
Waltham, MA 02154; (617) 899-0467
Dr. Richard J. Higgins, Principal Investigator
Dr. Robert L. Goldsmith, Business Official
DOE Grant No. DE-FG02-94ER81724
Amount: \$75,000

The selective permeation of gases through thin films of carbon-60 (Buckminsterfullerene) has been suggested as a possible application of this novel form of carbon. Indeed, substantial differences have been demonstrated in the rates of desorption of gases from

crystalline powders of C-60 and C-70. Whereas various carbon adsorbents are routinely used for gas separation and carbon-based permselective membranes have been reported, no adsorbent or amorphous carbon membrane has the inherent advantage of the geometrically-fixed "pore size distribution" characteristic of fullerene crystals. Therefore, the opportunity exists for highly selective permeation behavior if these materials could be made into thin films on a practical substrate. The planned technical approach involves fabrication of films of C-60 on inorganic supports. The focus will be on a low-cost, slip casting technique that takes advantage of the solubility behavior exhibited by fullerenes in several organic solvents. This organic "slip" will be applied to a microporous layer of gamma alumina with about 2 nm pores prepared on commercial ceramic ultrafiltration membranes. This gamma alumina layer will be applied with techniques previously established. The resulting fullerene membranes will be tested for gas separation behavior and thermal stability at elevated temperatures.

Anticipated Results/Potential Commercial Applications as described by the awardee: The fullerene-based gas selective membranes to be developed, when adapted to inexpensive, high-surface-area, supports (as envisioned for Phase II work), would provide a highly efficient, new method of separating a wide range of gaseous components typically found in chemical, petrochemical, and refining processes.

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Improving the Performance of Conventional and Column Froth Flotation Cells--CQ, Inc., P.O.
Box 208, One Quality Center, Homer City, PA
15748; (412) 479-6016
Dr. Barbara J. Arnold, Principal Investigator
Mr. Clark D. Harrison, Business Official
DOE Grant No. DE-FG05-94ER81733
Amount: \$74,404

Because of more stringent sulfur dioxide emission restrictions imposed under the 1990 Clean Air Act Amendments and the importance of raw coal cost and processing cost, many domestic mining companies producing higher sulfur content coals will be forced out of business for quality and/or economic reasons. This situation may force the closure of

marginal operations that are vital to many state economies. However, studies indicate that many higher sulfur coals may remain acceptable as feed stocks if more efficient fine coal cleaning technologies can be developed or conventional fine coal cleaning technologies can be improved. Because of this need and since many existing coal processing facilities employ some type of conventional or column flotation circuit, improving the efficiency of these existing technologies would provide the greatest benefit. This project will investigate the effects of high-shear pretreatment of coal feed on froth flotation performance and chemical requirements. The Phase I objective is to improve Btu recovery and increase pyrite rejection while reducing chemical costs. This pretreatment will enhance collector selectivity and better disperse the collector to make these improvements.

Anticipated Results/Potential Commercial Applications as described by the awardee: By subjecting conventional or column flotation feed and/or chemical additives to high-shear pretreatment, increases in Btu recovery and pyrite rejection should occur with lower chemical additive costs. Should this be successful, coal froth flotation circuits in cleaning plants in this country and abroad could be retrofitted with the in-line high-shear treatment device. The improved efficiency of the flotation circuit could possibly allow some high-sulfur, high-cost facilities to remain competitive.

51

Selective Comminution of Coal for Enhanced Removal of Mineral Matter--Energy and Environmental Research Corporation, 18 Mason, Irvine, CA 92718; (714) 859-8851

Mr. Jerald A. Cole, Principal Investigator
Dr. Roy Payne, Business Official
DOE Grant No. DE-FG03-94ER81753
Amount: \$75,000

On-line processing of coal prior to combustion in pulverized coal boilers involves first crushing the bulk coal. Crushed coal is then conveyed on weigh-belt feeders to large hammer mills where it is reduced to its final size. Before delivery to the burners, the pulverized coal is aerodynamically classified in cyclones or similar inertial separators to remove larger coal particles and denser mineral

matter. The pulverization process is non-selective, however, and produces fine mineral matter than can pass through the classifiers and contribute to ash fouling and emissions of toxic metals and sulfur oxides. In contrast, the selective comminution process can soften and fragment the carbonaceous matrix of crushed coal prior to pulverizing, without affecting the pyritic and quartz mineral components. This reduces the amount of energy needed for pulverization and the fineness to which mineral inclusions are ground, making the final aerodynamic classification process more effective. In contrast with density-based separation processes, such as flotation, selective comminution can be performed on-line and does not require post treatment such as washing and drying. During Phase I the effectiveness of selective comminution will be evaluated for dependence on coal type. The total amount of energy required to effect separation of mineral matter will be determined and compared with conventional practices for achieving similar levels of coal cleaning.

Anticipated Results/Potential Commercial Applications as described by the awardee: This effort will lead to the development of a process for reduction of pollutant and toxic metals emissions resulting from the burning of coal. Commercial applications for the process will be in existing and future pulverized-coal-fired power equipment. Application of this technology will not only lead to reduced emissions and resultant reductions in post-combustion cleanup costs, but will also lead directly to lower maintenance costs and longer plant life.

52

An Optical Gas Temperature Probe for High Temperature Fossil Fuel Process Streams--ERC, Inc., 205 Research Park Drive, P.O. Box 417, Tullahoma, TN 37388; (615) 455-9915

Dr. Y. C. L. Susan Wu, Principal Investigator
Mr. Richard S. Lin, Business Official
DOE Grant No. DE-FG05-94ER81762
Amount: \$74,894

This project concerns an innovative concept for an optical gas temperature probe which will have the capability of making direct measurements of gas temperature in hot (>1500 K) process streams of coal combustion systems and large-scale powerplant

facilities. Having the means for direct gas temperature measurements at strategic locations along a process flow path would provide a valuable tool for fossil fueled combustion systems and other applications such as power utilities, cement kilns, and waste incinerators. Direct gas temperature measurement allows characterization of the gas stream and system thermodynamic performance, providing a means for operator action to monitor, control, and optimize the system, as well as diagnose potential/hazardous problems. The Phase I technical approach is that of taking a proven optical diagnostic technique for measurement of high temperature gases (sodium line reversal) and miniaturizing the components of that technique to produce a temperature probe. This temperature monitoring system realized with the probe and its computer driven peripherals will be accurate, reliable, robust, and affordable. Phase I research will determine the feasibility of the optical gas temperature probe. It will focus on verifying the theory of its operation and defining of a conceptual design for a probe prototype. The conceptual design will include all features and needs of the probe including its optimum geometry, the probe housing, packaged miniaturized optics, its operation, and its facility needs. In Phase II a prototype of the optical gas temperature probe will be fabricated, and its capability verified in the laboratory and in the field.

Anticipated Results/Potential Commercial Applications as described by the awardee: The research is expected to provide an accurate, reliable, and affordable optical gas temperature probe and monitoring system allowing direct measurement of high temperature process streams (>1500 K) currently not practical with state-of-the-art diagnostics. It would leave a substantial commercial market in both research applications and in industry. University, federal, and industrial laboratories require direct gas temperature measurements for research on burners or larger scale combustor and process gas streams. Large industrial facilities (powerplants, manufacturing) represent a market for the probe as a device for process monitoring and control.

53

Pulverizer Modification for Pyrite Separation at the Power Plant--EXPORTech Company, Inc.,

P.O. Box 588, New Kensington, PA 15068-0588;
(412) 337-4415

Dr. Robin R. Oder, Principal Investigator

Mrs. Marcia R. Oder, Business Official

DOE Grant No. DE-FG05-94ER81764

Amount: \$74,977

In Phase I, a preliminary engineering design and cost estimate will be prepared for a one ton per hour (TPH) skid-mounted instrument-controlled coal cleaning pilot unit to be built and operated in Phase II. The pilot unit will consist of a modified air swept ring/roller pilot mill with attached magnetic separator. The unit is designed for separation of pyrites and other minerals from the internal circulating load of the roller mill when preparing minus 200 mesh coal for direct firing. The unit will be used in Phase II to demonstrate the efficiency of the ring/roller mill-magnetic separator combination in preparing low sulfur and low ash pulverized coal. The team will also prepare a conceptual estimate of the cost to build or to retrofit a commercial pre-combustion raw coal desulfurization unit consisting of a dry magnetic separator attached to and treating a portion of the high sulfur internal circulating load of a 50 TPH pulverizer producing 70%-80% minus 200 mesh clean coal.

Anticipated Results/Potential Commercial Applications as described by the awardee: This project could lead to new mills for pulverization and desulfurization of direct fired coal at power plants, steel mills, or other industrial sites, as well as for direct-fired coal pulverizer retrofits and minerals beneficiation.

54

Fluid Bed Combustor Compliance Coal Production--Grand Forks Activation Technologies,
120 North Washington Street, Grand Forks, ND
58203-3451; (701) 772-1733

Dr. Curtis L. Knudson, Principal Investigator

Dr. Curtis L. Knudson, Business Official

DOE Grant No. DE-FG02-94ER81773

Amount: \$69,577

Many low rank coals (especially lignites) have only marginally high sulfur contents, resulting in emissions of 2 to 3 pounds of sulfur dioxide (SO₂) per million Btu. This sulfur is present in about equal

amounts of pyritic, sulfatic, and organic sulfur. Therefore, physical cleaning methods are typically not applicable. However, these coals have high oxygen contents, and much of this oxygen is present in carboxylic acid functionalities that could provide sites for calcium ion exchange. Calcium could be incorporated into the coal structure, close to the sulfur, where it could efficiently trap sulfur during fluid bed combustion. Thus, the calcium-exchanged material would be combustible as a compliance coal, eliminating the need for mechanically intensive scrubbing or sorbent injection techniques. The ash content of the coal may be somewhat higher, but the total plant solids would be less and solids handling would be simpler. In Phase I, the method of ion exchanging coal with calcium in a simulated stockpile will be investigated, as well as the performance of the product in a small fluid bed combustor (FBC).

Anticipated Results/Potential Commercial Applications as described by the awardee: Demonstration of the economic production of compliance FBC fuels from moderately high sulfur coals should increase their marketability. Capital and operating costs of FBCs would be lower, encouraging their usage. This would be environmentally beneficial, since FBC nitrogen oxide emission levels are normally within EPA compliance limits. Phase II of this effort will integrate coal company and FBC vendor participation in pilot-scale testing of the SO₂ control method.

55

A Low Nitrogen Oxide High Performance Power Systems (HIPPS) Coal/Gas Burner-- Johanson and Associates, Angwen Avenue, Route 7, Box 7336, Manchester, TN 37355; (615) 728-3229
Mr. Norman R. Johanson, Principal Investigator
Mr. Norman R. Johanson, Business Official
DOE Grant No. DE-FG05-94ER81794
Amount: \$74,935

This project will investigate an innovative burner for the control of oxides of nitrogen (NO_x) from the combustion of fossil fuel, i.e., coal and natural gas, and in the future extend to 100 percent coal to meet or exceed the requirements of the High Performance Power System (HIPPS). The HIPPS is a combined cycle power plant consisting of an indirectly fired

Brayton topping cycle and a conventional Rankine bottoming cycle with goals of an overall efficiency of 47 percent and NO_x levels at or below 0.15 lb/MMBtu (=100 ppm). The goal of Phase I is to test an advanced primary combustor developed at the University of Tennessee Space Institute and configured with internal natural gas reburning which in concept could be used in the High Temperature Advanced Furnace in the HIPPS program as well as a replacement for conventional wall-mounted burners in pulverized-coal fired utility boilers. Additionally in Phase I, the combustor will be scaled up from the current 6 MMBtu/hr to a 25 MMBtu/hr furnace-wall-mounted configuration and tested during Phase II, in a 25 to 50 MMBtu/hr test facility. A previous short-term test using this combustor configuration has produced NO_x emissions with coal firing that were slightly below 0.3 lb/MMBtu when propane reburning supplied 14% of the total Btu input. By testing in Phase I with lower primary stoichiometry and increased reburning rate, it may be possible to achieve NO_x emissions of 0.15 lb/MMBtu or lower with propane or natural gas reburning supply equal to 35% of the total Btu input. During testing of this combustor 99.3% carbon conversion was achieved in long term 100% coal firing tests. The burner-replacement which will be scaled up to a 100 MMBtu/hr commercial configuration by the end of Phase II, represents an advanced concept with the potential for ultra-low NO_x in a furnace-wall-mounted configuration.

Anticipated Results/Potential Commercial Applications as described by the awardee: The anticipated result of this project will be that the existing data can be extrapolated to the HIPPS NO_x requirements of 0.15 lbs/MMBtu/hr using 65 percent pulverized coal and 35 percent natural gas. Application to retrofit existing fossil steam generation plants can be realized should the results be positive.

Low Cost Synthesis of Nanocrystalline Silicon Carbide Starting with Fullerene Precursors--
Materials and Electrochemical Research Corporation,
7960 South Kolb Road, Tucson, AZ 85706; (602)
574-1980

Dr. S. Guha, Principal Investigator
Dr. R. O. Loutfy, Business Official
DOE Grant No. DE-FG02-94ER81803
Amount: \$75,000

A novel technique for the synthesis of nanocrystalline silicon carbide (SiC) powders is planned starting with a silicon-based precursor and fullerene compounds as the raw materials. The reactivity of fullerenes, combined with previously demonstrated results in the synthesis of limited quantities of such noncrystalline SiC powders using a spark erosion technique, form the basis of this concept. Such processing will be carried out under a liquid solvent envelope thereby preventing exposure of the highly reactive SiC powder surfaces to the ambient atmosphere. Such nanocrystalline SiC powder with good purity is expected to exhibit excellent low temperature sintering characteristics which will lead to fully dense SiC components obtainable even with low temperature processing. The Phase I project will involve demonstrating feasibility of producing commercially significant quantities of nanocrystalline SiC and characterizing their microstructure and sinterability characteristics.

Anticipated Results/Potential Commercial Applications as described by the awardee: Nanocrystalline SiC powders with low impurity content and good sintering characteristics would find applications in engine components for both aerospace and automobile engines. Further, this technology, if demonstrated feasible, could be easily extended to the synthesis of nanocrystalline tungsten carbide and other carbide powders.

Energy Reduction in Ball Mill Grinding--
Mountain States R&D International, Inc., and
Arentzen Associates, Joint Venture, P.O. Box 310,
Vail, AZ 85641; (602) 624-7990

Mr. Charles Arentzen, Principal Investigator
Dr. Roshan B. Bhappu, Business Official
DOE Grant No. DE-FG05-94ER81816
Amount: \$37,190

Comminution of minerals by ball milling is energy intensive. Energy efficiency of ball milling ranges from less than 1 percent to 10 percent. Breakage by crushing is higher in efficiency but is impractical for production of a fine meshed product. It has been established in laboratory tests that high velocity impact breakage of particles results in complete breakage whereas low velocity impacts of the same kinetic energy result in reduced or no breakage. Since shattered particles from impact breakage fly out of the impact zone, excessive impact energy will be wasted. In Phase I a series of laboratory single particle breakage tests on hard coal will evaluate kinetic energy required to break particles completely at each impact. Based on particle breakage efficiency, a coal feed size and make up media size will be calculated. Batch mill tests will be made in a standard mill and with a modification to the mill. By modifying the mill, a control of impact energy can be effected and the process intensified. Comparative energy consumption versus grind will define energy savings and provide data for Phase II continuous pilot plant testing.

Anticipated Results/Potential Commercial Applications as described by the awardee: Over 25 percent reduction of energy in coal grinding is anticipated by the proposed method. Additional benefits such as compressed grind, reduced media consumption, and fewer slimes will result. The technique has application to new and presently installed autogenous and semi-autogenous ball and pebble mills. World wide use for ore, cement, and stone processing will result in major savings in energy. Reduced milling costs will lower the cost of coal slurry for beneficiation, transport, and direct firing.

Flame Monitoring and Optimization of Coal-Fired Burners Based on Frequency Spectra Analysis--PSI PowerServe, 20 New England Business Center, Andover, MA 01810-1077; (508) 689-0003

Dr. Mark J. Khesin, Principal Investigator
Mr. Stephen A. Johnson, Business Official
DOE Grant No. DE-FG02-94ER81835
Amount: \$75,000

This project will explore the development of a new method for characterizing and optimizing performance of coal burners, by analyzing frequency spectra of coal flames obtained from the existing flame scanners. Most industrial and utility boilers are presently equipped with flame monitoring devices (flame scanners) for individual burners. The sole function of these scanners is to detect the presence of flame for burner management systems. The input to a flame scanner (flame signal) consists of two components, intensity and temporal fluctuations; one or both of these components can be used for flame detection. Over the years, numerous data and observations have been accumulated suggesting that the temporal frequency component of the flame signal (often called "flame signature") can be utilized to develop a powerful diagnostic tool to characterize flame performance. The overall objective of this project is to improve the performance of conventional and advanced combustors by relating flame frequency signatures of individual burner flames to flame stability, efficiency, and emissions. This innovation will allow NO_x emissions and optimize operation of individual burners. In Phase I, a new algorithm will be developed and tested for processing flame frequency spectra from conventional flame scanners for coal-fired, low-NO_x burners. This new algorithm will be based on computer processing of relative amplitudes of temporal spectra at different frequency bands. The algorithm is expected to show strong correlation with flame characteristics and could be used to evaluate flame stability, fuel-to-air ratio, unburned combustibles, and NO_x emissions. In Phase II the results will be tested on a large scale at several industrial and utility boilers equipped with different types of burners. The results will be commercialized in the form of new products (software packages and new flame monitoring systems).

Anticipated Results/Potential Commercial Applications as described by the awardee: A new algorithm is formed from the existing burner flame scanner signals and based on a computer processing technique. The algorithm will use flame signatures to characterize the performance of individual burners. It will add a new diagnostic and optimization tool to fossil power plants, particularly to coal-fired units equipped with low-NO_x burners.

Development of an Innovative, Low Cost, Continuous Process for the Production of Nanoscale Silicon Carbide--PSI Technology Company, 20 New England Business Center, Andover, MA 01810-1077; (508) 689-0003

Dr. Joseph J. Helble, Principal Investigator
Dr. Anthony N. Pirri, Business Official
DOE Grant No. DE-FG02-94ER81836
Amount: \$75,000

Advanced electric power generation systems that are under development must generate high gas temperatures to improve cycle efficiencies and minimize effects on the environment. These high temperatures will require the use of ceramic materials in all or part of the system. Silicon carbide (SiC) is the ceramic best suited to meet this need. However, large grain sizes in commercial SiC materials make component fabrication costly and energy intensive. By reducing the grains to the nanoscale (10⁻⁹ meter) range, more cost effective and flexible processing may become feasible. In Phase I, a novel, high temperature, continuous aerosol method for producing nanoscale SiC powders in a flow reactor will be investigated. By spraying a reactive mixture into a high temperature environment, it is believed that nanoscale SiC can be produced without agglomeration or contamination. Phase I will focus on the production of nanoscale SiC powder using inexpensive precursors to demonstrate process feasibility. In Phase II, large quantities of SiC will be produced. Detailed sintering and mechanical properties testing will then be conducted to demonstrate the improved performance associated with nanoscale SiC.

Anticipated Results/Potential Commercial Applications as described by the awardee: A low cost process for the production of nanoscale SiC would

have broad applications. Currently, conventional micrometer-grained SiC is being used or considered for wear parts, cutting tools, high temperature engine components, abrasives, and structural materials. Improvements in material strength and reductions in sintering energy requirements made possible by the use of nanoscale grains should greatly increase the use of this material.

60

Fullerene Based Catalysts for Heavy Oil Upgrading--TDA Research, Inc., 12345 West 52nd Avenue, Wheat Ridge, CO 80033; (303) 940-2301
Dr. William L. Bell, Principal Investigator
Mr. Michael E. Karpuk, Business Official
DOE Grant No. DE-FG03-94ER81879
Amount: \$75,000

Heavy oils, including residues from crude oil distillation (resids), represent an abundant energy resource that is not fully utilized. It has been estimated that if only 20% of these crudes could be recovered, they would produce 1.27 million barrels of oil per day for the next 25 years. Use of heavy oils requires catalytic hydrogenation for removal of sulfur and nitrogen, and to lower the boiling range. Improved catalysts for heavy oil upgrading are highly desirable, and a promising area for improvement is the use of carbon catalyst supports, which show enhanced activity over traditional alumina supports. The recent discovery of fullerene carbon now offers the potential for preparation of improved carbon-supported catalysts. Fullerene-based catalysts in which nanoscale metal particles are deposited onto a carbon soot produced in conjunction with fullerene carbon will be investigated. This soot has been shown to possess remarkable properties that should be ideal for the hydroprocessing of heavy oils and resids. In Phase I the fullerene-based catalysts will be prepared, and screening tests with model systems will be conducted to identify effective catalysts. Phase I research will also test the best candidate catalysts with authentic samples of heavy oils and compare the results with catalysts currently in use. It will include an engineering analysis to determine the cost-effectiveness of the new catalysts. Phase II will systematically investigate the fullerene-based catalysts to achieve high performance, followed by commercialization in Phase III.

Anticipated Results/Potential Commercial Applications as described by the awardee: A successful project will lead to improved fullerene-based catalysts for use in heavy oil upgrading, as well as other possible applications. Improved catalysts for the intended application will lower the cost of converting heavy oils to more valuable materials.

61

A Coal On-Line Process Control Analyzer--Tri-Valley Research, 3590 Churchill Court, Pleasanton, CA 94588; (510) 846-6991
Dr. Robert M. Pearson, Principal Investigator
Mr. Paul Anderson, Business Official
DOE Grant No. DE-FG03-94ER81893
Amount: \$74,750

An analytical instrument capable of selecting coal blends that meet fuel and sulfur dioxide requirements with minimum post combustion emissions will be assembled and demonstrated in Phase I. The analyzer will use nuclear magnetic resonance to measure the carbon, hydrogen, and the moisture contents of coal and x-ray fluorescence to measure its ash and sulfur contents. This approach to coal evaluation recognizes that a complete elemental analysis is not necessary for the calculation of heat value and environmental impact of coals as they are used by most utility boilers. A reliable moisture analysis is essential in the evaluation of a coal's utility. A nuclear magnetic resonance spectrometer can quantitatively measure the various types of water found in coal plus the concentration of hydrogen bound to carbon atoms. Those measurements together with the determination of ash and sulfur by x-ray fluorescence spectrometry allow the selection of coal blends that best meet the emissions and fuel requirements of utility boilers. The combined spectrometer can be configured either as a small, relatively inexpensive laboratory device to measure individual samples sequentially, or as an on-line dynamic process control analyzer to characterize coal streams of any size.

Anticipated Results/Potential Commercial Applications as described by the awardee: This coal analyzer will be designed for operation by plant operators either on-line in the field, or in a laboratory. It will provide low cost real-time

measurements to characterize coal at mines, transfer stations, gasification or liquefaction plants, blending facilities to select coal blends which will meet

emission standards when burned, or at utility boilers for combustion optimization.

ADVANCED ENVIRONMENTAL CONTROL TECHNOLOGY FOR FOSSIL ENERGY

62

Controlling Mercury and Selenium Emissions from Coal-Fired Combustors Using a Novel Regenerable Natural Product--ADA Technologies, Inc., 304 Inverness Way South, Suite 110, Englewood, CO 80112; (303) 792-5615

Mr. Richard J. Schlager, Principal Investigator

Dr. Michael D. Durham, Business Official

DOE Grant No. DE-FG02-94ER81692

Amount: \$74,984

Fossil fuel combustion sources are the largest single contributor of atmospheric mercury emissions and the second largest contributor of atmospheric selenium. Of all the trace metals contained in coal, mercury and selenium are of greatest concern since they are the most volatile of the metals, they are widespread and relatively toxic, and they deposit in biosystems. In anticipation of future emissions regulations, there is a need to develop measures that will control these specific metals. These metals are difficult to collect because of unusual chemical and physical properties. Although selenium is removed in various degrees by flue gas desulfurization systems, control systems are not designed specifically to control selenium. Existing mercury control systems rely on the use of sorbents or wet-scrubbing equipment. In addition, once the mercury is captured, these sorbents may become hazardous wastes that must be disposed of. Furthermore, control systems do not provide consistent removal efficiencies for mercury. Therefore, a unique naturally-occurring sorbent to capture mercury and selenium will be developed in Phase I. A significant benefit of the sorbent is its regenerability, which allows the adsorbed metals to be recovered for re-use and eliminates the generation of hazardous wastes. Process economics are expected to be favorable since the sorbent is a re-cycled natural product, it can be regenerated for re-use, and the adsorbed metals can be recovered.

Anticipated Results/Potential Commercial Applications as described by the awardee: Successful development of the proposed sorbent will provide coal-fired combustors with a single package that will effectively remove selenium and mercury from flue gas streams. Solid waste volumes associated with existing control technologies will virtually be eliminated using the proposed sorbent. Critical technical and economic issues will be addressed during Phase I, and scaled-up field tests are planned for Phase II.

63

Improved Hot Stream Cleanup Using an In-Situ Multi-Gas Monitor--Advanced Fuel Research and On-Line Technologies Inc., 87 Church Street, P.O. Box 380379, East Hartford, CT 06138-0379; (203) 528-9806

Dr. Peter R. Solomon, Principal Investigator

Dr. David G. Hamblen, Business Official

DOE Grant No. DE-FG05-94ER81694

Amount: \$74,983

Removal of contaminants from hot gas streams fed to downstream equipment is essential to successful development of advanced coal utilization and conversion processes. The operation and optimization of such removal process often requires diagnostic instrumentation to measure concentrations and temperatures of contaminant species. One objective is the development of an in-situ methods for simultaneously measuring NO, N₂O, NO₂, NH₃, CO, SO₂, CO₃, HCL, and air toxics. The in-situ sensor will employ a state-of-the-art Fourier Transform Infrared (FT-IR) process spectrometer. Robust software is being developed for this system for gas quantitative analysis, even in the presence of high H₂O concentrations. To create an in-situ probe, the FT-IR sensor will be coupled to a porous ceramic diffusion cell. This cell is inserted into the hot gas stream and because of the diffusion through the

porous wall driven by the gas velocity, the cell maintains a gas concentration equal to that in the outer stream without particulates. The application of this technology will be developed and demonstrated by controlling a Selective Non-Catalytic Reduction (SNCR) for the control of NO_x and NH_3 (which is an unwanted by-product). The objective of Phase I is to design, build, and test a prototype system which couples the FT-IR sensor with the porous in-situ diffusion cell to provide inputs to a commercial process. After laboratory testing and calibration of the sensor, a field test will be performed in a pilot plant which has extensive monitoring facilities.

Anticipated Results/Potential Commercial Applications as described by the awardee: The technology will be ideally timed to meet a large and growing requirement in industry for analytical instruments to monitor process streams, effluent pollution and ambient air quality. There are many applications where the ability to measure multiple parameters with a single instrument give FT spectroscopy a significant advantage. Specific applications of a multi-gas monitor which can measure ammonia are for SNCR processes for NO_x control, monitoring NH_3 in coke production facilities, and monitoring of NH_3 and other gases in chemical production facilities. There are also important applications in monitoring of air toxics and any other species.

64

An Optical Technique for Non-Intrusive Characterization of Fine Particulates in Flue Gas Streams--Aerometrics, Inc., 550 Del Rey Avenue, Sunnyvale, CA 94086; (408) 738-6688
Dr. William D. Bachalo, Principal Investigator
Dr. William D. Bachalo, Business Official
DOE Grant No. DE-FG03-94ER81699
Amount: \$74,694

The feasibility of using a novel light scattering intensity ratio technique for the simultaneous measurements of the speed and size of non-spherical particles will be examined in Phase I. The technique makes use of two concentric laser beams with different diameters and the amplitude of the signals from the light scattered by the particles traveling through the probe volume to infer their size and

speed. The sizing of irregular particles is accomplished by using near forward collection of the scattered light, in which depolarization of the scattered light by irregular particles is not significant, and the scattered light intensity is only sensitive to the projected area of the particles. The planned technique will have the ability to (1) size both spherical and non-spherical particles, (2) measure the particle number density and volume flux, and (3) measure the particle speed. The objectives of Phase I are to: (1) investigate the feasibility of using this novel technique for non-spherical particle size measurements, (2) conduct calibration measurements of spherical and non-spherical particles, and (3) study the feasibility of using laser diode technologies for compact probe development.

Anticipated Results/Potential Commercial Applications as described by the awardee: The planned laser diagnostic technique for particle sizing has a wide range of applications in practical environments. It can be used for the diagnostics of spherical and non-spherical particles present in flue gas streams, coal-water slurries, soot conglomerates, fly ash, and combustion generated particles. There is presently no single instrument which can successfully be used for measuring particles in such a wide range of industrial applications.

65

A Ceramic Material and Process for Use in Monolithic Ceramic Cross-Flow Filters--Blasch Precision Ceramics, 99 Cordell Road, Schenectady, NY 12304; (518) 372-9416
Mr. David A. Larsen, Principal Investigator
Mr. David W. Bobrek, Business Official
DOE Grant No. DE-FG02-94ER81718
Amount: \$74,937

Ceramic cross-flow filters have been designed to provide high temperature, high pressure removal of particulates from hot gas streams in coal fueled power systems, with the benefit of high surface area per unit volume. However, further ceramic technology is needed on cross-flow filters to improve both effectiveness and reliability. An important need has been identified as a one-piece monolithic ceramic cross-flow filter, rather than the present segmented filter that has been known to delaminate in service.

This delamination allows particulates to bypass the filter, which could lead to costly damage to downstream turbines and subsequent failure to meet environmental regulations pertaining to stack gas emissions. Current ceramic technology has proved incapable of forming a complex one-piece shape of this nature with an acceptable permeable, porous ceramic material. A unique and proprietary injection mold ceramic forming process has been used for years to produce complex one piece monolithic shapes commercially, but of a non-permeable nature. The development of a permeable ceramic composition for this process represents a significant effort. In Phase I, the aim is to demonstrate the feasibility of a novel technology where a permeable, porous ceramic material is formed with this process, targeted to meet the filtration and environmental requirements of cross-flow filters. With this material and process, a much more reliable, effective monolithic ceramic cross-flow filter can evolve.

Anticipated Results/Potential Commercial Applications as described by the awardee: Phase I results are expected to show which of several ceramic composition variations produce favorable permeability and hot strength properties suitable for cross-flow filter application. The Phase II objective will be prototype production and field testing of monolithic ceramic cross-flow filters to demonstrate a new level of effective, reliable removal of particulates in hot gas streams, in coal fired power systems. The new filter design is expected to significantly reduce stack emissions and reduce costly downstream turbine damage and downtime in coal-fired power systems.

66

A Mercury Compound Luminescence Determination Method and Apparatus--Brooks Rand, Ltd., 3950 Sixth Avenue, Northwest, Seattle, WA 98107; (206) 632-6206
Dr. Craig W. Brown, Principal Investigator
Mr. Richard J. Brooks, Business Official
DOE Grant No. DE-FG03-94ER81719
Amount: \$60,217

This project investigates the molecular electronic spectra of mercury compounds suspected to be present in coal fired power plant flue gas. These compounds include mercuric chloride, dimethyl

mercury, and monomethyl mercuric salts (methyl mercury). Methyl mercury is particularly important because of its toxicity and propensity for bioaccumulation. Prior chemical methods indicated its presence in flue gas, but are known to be unreliable. This project seeks a reliable direct spectroscopic method of performing methyl mercury determinations in flue gases. The Phase I research emphasizes steady-state luminescence. In general, luminescence-based quantitation methods can be more sensitive than light absorption alone. In addition, time resolved methods can yield determinations even in the presence of interferences from compounds with overlapping spectra. The elegant time resolved methods cannot be used, however, unless the target compounds actually luminesce and the steady state luminescence is characterized. This characterization is the goal of this Phase I research. The results will indicate the feasibility of luminescence-based detection, and will set the stage for research and development to apply time resolved methods.

Anticipated Results/Potential Commercial Applications as described by the awardee: Potential commercial applications of anticipated results include mercury monitoring systems. In particular, a turn key system is targeted that will implement luminescence based quantitation of methyl mercury in flue gas. This system is intended to provide results in field conditions, and in near real time.

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An In-Situ Microanalysis of Coal Flyash: The Feasibility of Correlating Organic Surface Chemistry and Particle Composition--Charles Evans and Associates, 301 Chesapeake Drive, Redwood City, CA 94063; (415) 369-4567
Dr. Jang-Jung Lee, Principal Investigator
Mr. James E. Plank, Business Official
DOE Grant No. DE-FG03-94ER81725
Amount: \$74,908

Coal flyash, one of the most widely studied types of pollutant particles, is a complex mixture which encompasses a broad range of particle compositions, sizes and morphologies. Organic compounds including polycyclic organic matter (POM) can adsorb onto these particles during coal combustion processes. Many of the POM compounds and their

derivatives are known to be carcinogens or mutagens. The POM also may undergo reactions on particle surfaces to yield chemical products presenting greater health risks. The nature of the particle surface plays a critical role in these POM transformations. Particle-adsorbed POMs have been studied with solvent extraction analysis of large collections of flyash particles. However, significant heterogeneity among particles as well as more surface-specific chemistry may not be adequately detected with these techniques. In order to fully understand these surface chemistries, a detailed surface and bulk microanalysis of individual particles is needed. A unique time-of-flight secondary ion mass spectrometer (TOF-SIMS) will be used to evaluate the in-situ surface chemistry of coal flyash. Secondary ions characteristic of the near surface composition of the sample surface are produced by a low intensity, pulsed primary ion beam. This sensitive surface mass spectrometry technique provides the advantages of high mass resolution, large mass ranges, and high sensitivity for in-situ microanalysis of elements, organic and inorganic species. The high spatial resolution of TOF-SIMS ion imaging is essential for direct analysis of individual flyash particles. The emphasis of Phase I will be to determine the feasibility of correlating flyash surface composition and POM coverage and reactivity. This research will emphasize the study of particle surfaces, including the ability of these surfaces to concentrate and/or transform environmentally significant compounds such as POM. This feasibility study will also attempt to correlate particle surface characteristics with reaction processes such as POM photolysis or nitration.

Anticipated Results/Potential Commercial Applications as described by the awardee: The analytical protocols which would be developed as a result of this research could significantly facilitate future monitoring of the chemical composition of combustion-generated particles. These analytical methods could also provide sensitive and specific chemical analysis of various airborne particulates. The development of specialized organic microanalysis techniques for particulates could also lead to the development of specialized instrumentation for this type of characterization. This instrumentation would find markets in environmental clean-up and monitoring industries as well as ultraclean manufacturing industries such as semiconductor industry.

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Coal Ash Tiles by Microwave Processing--
Chemat Technology, Inc., 19365 Business Center Drive, Suite 8, Northridge, CA 91324; (818) 727-9786

Mr. Haixing Zheng, Principal Investigator

Mr. Patrick Lin, Business Official

DOE Grant No. DE-FG03-94ER81727

Amount: \$75,000

This Phase I project considers the use of microwave heating for the production of tiles and bricks from coal-derived ash. The generation of undesirable ash from coal-fired power plants has become a serious environmental problem. Coal-fired power plants are responsible for the annual production of more than sixty million tons of ash in the United States. A typical 800 megawatt station consumes 7500 tons of coal and generates 1000 tons of bottom and fly ash daily. Ash contains heavy metals, and the disposal of this material in landfills is drawing increased attention. Much of this attention is warranted by the fact that ash is a finely divided oxide powder with a large surface area. Since the leaching of a constituent from a powder is proportional to its surface area, it would be desirable to design a method of consolidation involving surface area reduction. The interest in such a technique would be greatly increased if, in addition to volume and surface area reduction, the product had usefulness and commercial value. For example, tiles or bricks can be fabricated, but conventional methods of heating used in tile manufacturing require large flows of air which can cause air pollution. They are also time and energy consuming because it is relatively difficult to heat a powder. Microwave processing allows for low cost, volumetric, ultra-rapid, uniform heating without air pollution. Most types of ash absorb microwaves. However, if some do not, small amounts of a microwave coupler such as ferrous/ferric oxide may be added to form a microwave coupling mixture. Upon heating, the ashes will sinter and undergo a reduction in surface area. Under appropriate processing conditions, this would result in (1) the formation of a mechanically strong material shaped as a tile or brick, (2) encapsulation of heavy metals in a very stable glassy phase, and (3) elimination of the environmental issues associated with the starting material.

Anticipated Results/Potential Commercial Applications as described by the awardee: The successful development of this technology through Phases I and II would result in a new product with two fold commercial potential: (1) elimination of the cost of transportation, landfilling, insurance, and potential lawsuits emerging from landfilling of coal residues, and (2) introduction of new types of tiles, bricks, and construction materials to the market. The potential commercial applications of the microwaved coal-ash tiles are tiles and bricks for construction, paving, roofing, decoration, artificial reefs, low permeability liners for landfills, and all other applications of ceramic tiles.

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Electrolytic Polymer Cells for Carbon Dioxide Conversion--Eltron Research, Inc., 2830 Wilderness Place #E, Boulder, CO 80301; (303) 440-8008
Dr. Anthony F. Sammells, Principal Investigator
Ms. Eileen E. Sammells, Business Official
DOE Grant No. DE-FG02-94ER81749
Amount: \$74,998

This project is directed towards the development of electrolytic polymer cell technology, incorporating advanced electrocatalysts recently identified for the direct electrochemical conversion of carbon dioxide (CO_2) to useful chemical feedstocks. CO_2 will be supplied to the electrolytic cell cathode compartment as a concentrated stream originating from advanced flue gas technologies. Specific CO_2 reduction products of interest are ethylene ethanol, and propanol. Electrocatalytic cells to be investigated will be based upon both proton and hydroxide ion conducting polymer electrolyte membranes. Electrocatalysts for CO_2 reduction will favor high coverage by an adsorbed carbon monoxide intermediate which will be expected to permit low overpotentials associated with subsequent electron transfer leading to the efficient synthesis of hydrocarbons and alcohols. There are clear incentives for development of this technology which will both lower costs associated with important chemical feedstocks and decouple dependency for their synthesis upon imported oil, based upon consumption of a greenhouse emission gas.

Anticipated Results/Potential Commercial Applications as described by the awardee: This

project will result in characterizing an electrolytic technology compatible with the efficient and high rate conversion of carbon dioxide to commercial fuels and chemicals. Since these products are widely used and needed feedstock materials, this technology would be of significant economic and social benefit to the Nation by utilizing a significant greenhouse gas for their synthesis. This strategy will offset the cost of emissions control associated with advanced flue gas cleanup.

70

Flue Gas Cleanup Using a Novel Corona Generator--Environmental Elements Corporation, 3700 Koppers Street, P.O. Box 1318, Baltimore, MD 21203; (410) 368-7239
Dr. Paul L. Feldman, Principal Investigator
Dr. Paul L. Feldman, Business Official
DOE Grant No. DE-FG05-94ER81761
Amount: \$74,650

The Clean Air Act Amendments of 1990 will require more stringent control of emissions of gaseous contaminants such as sulfur oxides (SO_x), nitrogen oxides (NO_x), and the volatile air toxics. This trend toward more stringent air quality standards clashes with the demands of emerging markets: lower air pollution control equipment cost and higher collection efficiencies for these contaminants. This grant application is for the development of a superior method of applying corona chemistry. The Phase I project will study the effect of system variables such as geometry, residence time, type of energization, and polarity on pollutant removal efficiency and energy requirement. These results will indicate optimum conditions for which systems viability and economics can be determined for use as the basis for a decision to proceed to Phase II.

Anticipated Results/Potential Commercial Applications as described by the awardee: It is anticipated that a system based on this corona chemistry concept will be more economical than competitive systems for SO_x and NO_x control. It will be even more attractive if simultaneous control of volatile air toxics can also be demonstrated. The concept should find application in the industrial and utility power/combustion markets and in high temperature chemical processes such as petroleum

refining, cement, glass, and metallurgical applications.

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Laminar Flow Electrostatic Precipitation--
Environmental Elements Corporation, 3700 Koppers
Street, P.O. Box 1318, Baltimore, MD 21203; (410)
368-7239

Dr. Paul L. Feldman, Principal Investigator

Dr. Paul L. Feldman, Business Official

DOE Grant No. DE-FG05-94ER81760

Amount: \$74,965

Regulations governing the control of particulate emissions are becoming increasingly strict in terms of the control efficiencies they require. Several driving forces are responsible for this trend, foremost of which is the need to control toxic air emissions, such as trace metals and heavy organic compounds. Other driving forces include the Ambient Air Quality Regulations and state and local regulations for stack opacity. In each case, effective control translates to the high-efficiency removal of sub-micron particles. Unfortunately all particulate control devices are least efficient in the sub-micron region. High-efficiency control of particles in this region truly stresses the economic and reliability limits of conventional control equipment, and because 100% collection efficiency cannot be reached in conventional equipment, the cost of particulate removal increases rapidly as regulations force that level to be approached. What is needed is a device which is capable of 100% control, and laminar-flow electrostatic precipitation is known to have that capability. Although demonstrated in small-scale equipment, a practical design is needed which will allow laminar flow to be sustained on an industrial scale. Phase I will evaluate three options for exploiting laminar flow electrostatic precipitation as an ultra-high particulate collector in a practical and economic way.

Anticipated Results/Potential Commercial Applications as described by the awardee: It is anticipated that a wet laminar-flow precipitator design will be shown to be an effective and practical way to achieve total particulate control. Although widely applicable its greatest market potential should be in larger industrial and utility applications, such as power generation and waste incineration, as the best available means for high-

efficiency control of fine particulate matter as will be required in the future.

72

Simultaneous Hot Desulfurization and Improved Filtration in Coal Utilization Processes--Industrial Filter and Pump Manufacturing Company, Inc., 5900 Ogden Avenue, Cicero, IL 60650; (708) 656-7800

Mr. Paul Eggerstedt, Principal Investigator

Mr. Paul Eggerstedt, Business Official

DOE Grant No. DE-FG02-94ER81786

Amount: \$75,000

Although this Nation has some of the greatest coal reserves in the world, many of them will remain unusable until technology is developed to meet both Clean Air Act mandates and New Source Performance Standards (NSPS) for particulate, sulfur dioxide (SO_2), and nitrous oxide emissions, effectively and economically. Recent breakthroughs in particulate control, specifically ceramic filtration technology, have shown that NSPS limits on particulates can be achieved at high process temperatures, thereby minimizing thermal losses and system complexity. Experimentation with sorbents, particularly metal oxide sorbents, has resulted in promising SO_2 emissions level reduction. Moreover, spent metal oxides, such as those generated by steel manufacturing and smelting processes, have shown promise as candidates in SO_2 removal, on a much more cost effective basis. For example, preliminary testing using spent iron oxide dust from a steel mill basic oxygen furnace (BOF) has shown that, in comparison to an equivalent volume of a more traditional sorbent such as calcium carbonate, BOF dust can remove approximately three times as much SO_2 before exhaustion. Because the affinity for SO_2 is probably not limited to spent iron oxide dust, Phase I will pursue the testing of several spent metal oxides to determine which show high affinity for SO_2 capture in a laboratory setting. The most promising candidates from Phase I would then be evaluated in the Phase II effort to verify their sorbent capacity by using thermogravimetric analysis and to determine their additional capability as high temperature filter aids, after classifying to a specific particle size distribution. Ultimately, when utilized as a "once-through" sorbent in a combination with ceramic filtration technology, these spent metal oxides would

provide SO₂ removal and enhance filter performance in a most cost-effective manner.

Anticipated Results/Potential Commercial Applications as described by the awardee: Phase I results will show which spent metal oxides of those tested have the highest potential for SO₂ removal. The Phase II effort will show that these spent metal oxides can be of additional benefit as high temperature filter aids. By combining these sorbent and filter aid qualities with existing highly effective ceramic filtration technology, both particulate and SO₂ type emissions will be removed in a cost-effective manner. The availability of the spent metal oxides and the minimal processing required will allow this technology to be quickly developed and permit utility companies to utilize this Nation's high sulfur coal reserves while meeting existing emissions regulations.

73

Optical Diagnostic Instrumentation for Use in Hot Gas Streams--M. L. Energia, Inc., P. O. Box 1468, Princeton, NJ 08542-1468; (609) 799-7970
Dr. Moshe Lavid, Principal Investigator
Ms. Nira Lavid, Business Official
DOE Grant No. DE-FG05-94ER81801
Amount: \$75,000

A major obstacle to wider utilization of coal, tar sand, oil shale, and natural gas resources is environmental compliance. The employment of these abundant fuel resources is still fraught with the unacceptably copious emission of hazardous pollutants. In order to enforce compliance with emission control standards and to monitor the necessary clean up of hot and flue gas streams, a real-time, efficient, and reliable diagnostic system is needed. Current systems are expensive, delicate, and cumbersome. This project offers a novel optical diagnostic system capable of in-situ, real-time, and accurate monitoring of environmental pollutants. The main objective is to determine the feasibility of the planned system to accurately and in real time determine concentrations of polluting species generated by various combustion and chemical processes. This feasibility study encompasses the incorporation of readily available electro-optic components such as light source, fiber optics sensor, circular variable filter, Fabry-Perot interferometer,

and infrared detector into an advanced novel instrument. The Phase I effort is directed into three main tasks: (1) evaluation of the trade-off between the various components to yield best overall performance, (2) design and construction of a breadboard prototype for a single representative species (e.g., a selected optical wavelength), and (3) overall integration and testing. Phase I will provide the technical basis for extending the diagnostics to other species during Phase II. Once feasibility is proven, a prototype will be designed, constructed, and fully tested.

Anticipated Results/Potential Commercial Applications as described by the awardee: The optical diagnostic system will have a broad range of commercial applications. It will assist the energy and chemical industries and, in particular, advanced coal-fueled systems to comply with environmental regulations by providing a real-time and affordable diagnostic system. It will be widely used by the environmental enforcing agencies, Federal, state, and local, and by research and testing laboratories. The system will be used to monitor flue gas emissions from conventional combustion and chemical processes. Finally, because of its portability and rapid employment, it will also be used for emergency monitoring of accidents involving discharge of pollutants to the environment.

74

Development of Expansive Cements Using Dry Flue Gas Desulfurization Solid Wastes--Praxis Engineers, Inc., 852 North Hillview Drive, Milpitas, CA 95035; (408) 945-4282
Mr. Steven R. Hadley, Principal Investigator
Ms. Suzanne C. Shea, Business Official
DOE Grant No. DE-FG03-94ER81832
Amount: \$74,992

Dry flue gas desulfurization (dFGD) is an emerging advanced sulfur dioxide (SO₂) control system for pulverized coal-fired power plants with an estimated 20,000-MW generating capacity worldwide. In this method, excessive amounts of calcium hydroxide are used to capture the SO₂ in the flue gas. The fly ash from these facilities differs from conventional pulverized coal fly ash in that it contains substantial amounts of sulfur compounds and unreacted calcium hydroxide in addition to the coal ash-derived fly ash.

The relatively high ratio of calcium hydroxide to fly ash is theoretically very promising since both are known to form pozzolanic reaction products similar to cement hydration, suggesting that the economics of using these fly ashes in blended cement would be more favorable than those for conventional fly ashes. However, this potential has not been realized to date because the proportion of sulfur compounds in the dFGD wastes is too high. The proposed research will investigate the potential for producing a special class of cements, termed expansive cements, using a high proportion of dFGD wastes blended with Portland cement and another specific additive. This additive is designed to react with the sulfur compounds in the dFGD ashes and result in a small controlled expansion of the concrete before it achieves a hardened state. This early expansion would compensate for the eventual drying shrinkage that occurs in all Portland cement concretes, thereby reducing the tensile stresses in the aged concrete that can lead to cracking. During Phase I, the effects of the fly ash composition (rank of coal from which it originated) and the ratio of the expansion additive to the sulfur concentration in the dFGD ashes will be investigated. Based on these tests, the preliminary economics of producing a dFGD expansive cement will be developed and marketing strategies formulated. If the results of Phase I are encouraging, a Phase II program will be developed to quantify the engineering properties of concretes produced from dFGD fly ashes and demonstrate that all specifications for expansive cements required by applicable ASTM standards are satisfied.

Anticipated Results/Potential Commercial Applications as described by the awardee: The anticipated result of this project is development of the cement chemistry required to formulate expansive cements from dry flue gas desulfurization (dFGD) fly ashes. This technology will form the basis for production and marketing of blended expansive cements or cement additives using dFGD fly ash as a primary component. Three important benefits would result. First, the cost of landfill disposal of dFGD solid waste will be eliminated. Second, the energy cost for production of cement will be lowered because the addition of dFGD fly ash does not require the high-temperature processing and grinding used to produce conventional Portland cement. Third, the utilization of dFGD fly ash will reduce the mining requirements for cement kiln feed

materials, thereby reducing the associated environmental impact.

75

Toxic Materials Partitioning During Pulverized Coal Combustion: Measurement and Production--PSI PowerServe, 20 New England Business Center, Andover, MA 01810-1077; (508) 689-0003
Dr. Lawrence E. Bool, III, Principal Investigator
Mr. Stephen A. Johnson, Business Official
DOE Grant No. DE-FG02-94ER81834
Amount: \$75,000

Of the 189 species designated as toxic air pollutants by the Clean Air Act Amendments (CAAA), 37, including 11 metals, are found in effluent streams of coal-fired power plants. Future regulations may require utility operators to carefully monitor and reduce emissions of these toxic metals. However, very little is known about the fundamental transformations of these metals in combustion systems. Current models to predict emissions are based on existing information on metal emissions and are of limited usefulness in exploring emissions of novel fuel blends and boiler configurations. This project will both obtain fundamental information on partitioning mechanisms for three trace metals and develop a directly marketable tool to predict partitioning of these metals in utility boilers. These metals include arsenic, selenium, and mercury. In Phase I combustion studies will be used to determine the governing mechanisms for partitioning of the specified metals. A commercial software package, based on these mechanisms, will be developed to predict metal partitioning in utility boilers.

Anticipated Results/Potential Commercial Applications as described by the awardee: This project will both expand the fundamental knowledge of metal transformations during coal combustion and lead to a software package to predict metal partitioning in utility boilers. This package, will allow utility operators to determine the effect of coal choices on trace metal emissions. Further, the project will help utilities determine if existing particulate control devices provide adequate emissions control, or whether alternative methods must be used.

A Low Cost Method for Reducing Mercury Emissions in Fossil-Fuel Fired Power Plants--

Reaction Engineering International, 77 West 200 South, Suite 210, Salt Lake City, UT 84101; (801) 364-6925

Dr. Warren D. Owens, Principal Investigator

Dr. Michael P. Heap, Business Official

DOE Grant No. DE-FG03-94ER81846

Amount: \$74,997

Recently, there has been increased environmental concern about the emissions of mercury from combustion sources in the form of metal fumes or submicron particles. Naturally occurring mercury in a fuel vaporizes during combustion and then condenses as the combustion gases cool, leading to interesting challenges in the design and operation of equipment to clean the flue gases prior to stack release. Studies have indicated that mercury emissions can be reduced from coal fired power plants by injecting activated carbon or various sorbents. The drawback of these technologies is that they require considerable capital investment in equipment and material. The hypothesis that mercury emissions can be controlled using a low cost method of recycling fly ash from an air pollution device back into the flue gas stream without compromising the particulate emissions of the system will be explored. The approach used is based on both model/theoretical and experimental tasks. Process models and a pilot-scale coal fired facility will be used to answer this hypothesis in Phase I. Mercury adsorption behavior will be investigated using pulverized coal fly ash. The objective is to identify and quantify whether fly ash obtained from an air pollution control device can be recycled into the flue gas stream to control mercury emissions without compromising overall system performance and economics. More specifically, the knowledge generated in Phase I will be used to (1) identify how fly ash can be used most effectively to control mercury emissions from pulverized coal boilers, and (2) further define what tests are needed in a pilot/field demonstration for Phase II.

Anticipated Results/Potential Commercial Applications as described by the awardee: The results of this Phase I project will provide (1) the amount of residual fly ash carbon necessary for the control of mercury, (2) the governing mechanisms

controlling the capture of mercury in flue gas, the adsorption capacities of fly ash, the effect of gas-phase species and entrained particle interactions, and the effect of the form of mercury on fly ash capture efficiency, (3) the suitability of a fly ash recycle stream to enhance mercury capture and provide additional control for the system, and (4) the combustion/facility parameters that can be modified to determine the economic trade-off in combustion efficiency versus mercury capture efficiency.

Ultrasensitive In-Situ Detection of Toxic Flue

Emission--Science Research Laboratory, Inc., 15 Ward Street, Somerville, MA 02143; (617) 547-1122

Dr. Allen Flusberg, Principal Investigator

Dr. Jonah Jacob, Business Official

DOE Grant No. DE-FG02-94ER81855

Amount: \$74,940

The 1990 Clean Air Act amendments list nearly two hundred toxic materials that must be regulated. Among these are polycyclic aromatic hydrocarbons (PAHs), carcinogens that are associated with incomplete combustion and fine particulates. There is therefore a need for new technology to measure very low concentrations of such species at sites adjacent to coal-fired utilities, which are sources of PAHs. Extractive methods, in which a sealed sample of air is analyzed in a laboratory, are expensive and are inapplicable to continuous, in-situ monitoring of the concentrations of these toxic emissions. This project will study the development of an instrument called a tunable pulsed absorption diffractometer (TPAD) to fill this need. The basis of this instrument is the detection of a transient, volumetric diffraction grating that is formed after a pulsed laser beam is absorbed by toxic emissions present in the illuminated region. An instrument that utilizes a tunable, pulsed infrared laser can be tuned through the near-infrared absorption spectrum of PAHs to determine their concentration in the presence of other absorptive species. A TPAD will be sensitive to a concentration of a part-per-trillion toxic gas concentrations, orders of magnitude better than instruments based on other approaches to detect such toxic species. The Phase I feasibility study will be followed by a proof-of-principle Phase II demonstration. The construction and testing of a prototype instrument will take place in Phase III.

Anticipated Results/Potential Commercial Applications as described by the awardee: Once developed, the tunable pulsed, absorption diffractometer will be an essential tool for monitoring real-time, in-situ toxic PAH emission in the vicinity of coal-fired power plants, industrial sources of pollution, and heavy automobile traffic. Demand for these instruments will come from Federal, state, and local government agencies, as well as from the private sector.

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Development of an Electrochemical System for Carbon Dioxide Concentration--TDA Research, Inc., 12345 West 52nd Avenue, Wheat Ridge, CO 80033; (303) 940-2301

Dr. William L. Bell, Principal Investigator

Mr. Micheal E. Karpuk, Business Official

DOE Grant No. DE-FG03-94ER81883

Amount: \$75,000

Control of carbon dioxide (CO₂) emissions from the combustion of fossil fuels may become necessary to minimize global warming produced by the greenhouse effect. Separation of CO₂ from flue gases will increase the efficiency and lower the cost of processes to fix CO₂ chemically or otherwise prevent

its discharge into the atmosphere. Such a CO₂ transport system must operate at high efficiency to minimize the energy consumption and cost of reducing CO₂ emissions. This project will investigate a novel electrochemical system for the removal of CO₂ from the flue gas of coal-fired power plants. Previous work has demonstrated that electrochemical CO₂ separation systems can potentially operate at higher thermodynamic efficiency than others. A critical part of this system is a carrier molecule that can reversibly bind and release CO₂. The innovation is a class of water-soluble carriers for CO₂ transport and concentration. Phase I will prepare and test potential CO₂ carriers to identify those most effective in electrochemically transporting CO₂. Phase II will test the durability of the new carriers, and will design, construct, and test a prototype electrochemical process for CO₂ removal.

Anticipated Results/Potential Commercial Applications as described by the awardee: The successful project will develop a new system for CO₂ removal that can be used at fossil fuel burning power plants. This technology could lower the energy cost of minimizing CO₂ discharge. The system would be useful to the utilities that account for the majority of the Nation's electrical energy production, and has application in other areas where one component of a gas stream must be efficiently removed.

ADVANCED TECHNOLOGY FOR THE RECOVERY, STORAGE, AND UTILIZATION OF NATURAL GAS

79

Landfill Gas Conversion to a Contaminant-Free Methane-Carbon Dioxide Reformer Feedstock for Methanol Synthesis--Acrion Technologies, Inc., 9099 Bank Street, Cleveland, OH 44125; (216) 573-1187

Dr. William R. Brown, Principal Investigator

Dr. William R. Brown, Business Official

DOE Grant No. DE-FG02-94ER81690

Amount: \$74,979

Municipal landfills produce gas: several million standard cubic feet (SCF) per day from a modest landfill, and upwards to 5-10 million SCF/day from

large landfills. Gas generation of this magnitude continues long after landfill closure, perhaps for 15 to 20 years. Landfill gas (LFG) is roughly an equal mix of methane (CH₄) and carbon dioxide (CO₂), which becomes contaminated with many volatile trace compounds as it migrates through the landfill. LFG collection systems are installed primarily to prevent off-site migration and control odors; reduction of greenhouse gas emissions is an indirect benefit. Most collected LFG is simply flared to convert CH₄ to CO₂, a non-explosive, non-toxic, less potent greenhouse gas. Economic and technical barriers discourage energy recovery from LFG. The cost of avoided power in many areas does not justify the conversion of LFG to electricity, while the

technical difficulty of removing CO₂ and trace contaminants coupled with lack of natural gas pipeline access usually causes problems in the conversion of LFG to CH₄. Research is being conducted to further develop technology that converts raw LFG to a contaminant-free mixture of CH₄ and CO₂ to serve as reformer feedstock for methanol synthesis. No hazardous solvents or other separating agents are used; CO₂, an environmentally benign "green" solvent condensed directly from LFG, is used as cold liquid absorbent to remove LFG contaminants to below ppm levels. Temperature and pressure are selected to produce a contaminant-free mixture with the desired CH₄:CO₂ ratio for methanol synthesis, about 2.3:1. Methanol, easily stored and transported from a landfill, enjoys an expanding readily available market, and therefore could make LFG utilization profitable for relatively small landfills. The phase I objective is to demonstrate production of contaminant-free methanol synthesis feedstock gas from landfill gas by contaminant absorption with cold liquid CO₂. The amount of simulated LFG gas flowing to the liquid CO₂ absorption column will be about 30,000 to 40,000 SCF/day, a scale sufficient to demonstrate both technical and commercial viability to municipal landfill owners and operators.

Anticipated Results/Potential Commercial Applications as described by the awardee: Successful demonstration of LFG conversion to CH₄ synthesis feedstock will provide landfills with an attractive alternative to electricity or pipeline gas. Cold liquid CO₂ absorption of contaminants has wide applicability in gas processing beyond LFG treatment. Applications include acid gas removal from coal gasifier gas or from the partial oxidation of heavy hydrocarbons for the production of hydrogen or synthesis gas, acid gas removal from low quality natural gas, and Claus sulfur plant tail gas cleanup.

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Metal Monoliths for Conversion of Natural Gas to Liquid Fuel--Alabama Cryogenic Engineering, Inc., P.O. Box 2470, Huntsville, AL 35804; (205) 536-8629

Dr. Michael L. Dingus, Principal Investigator
Ms. Mary T. Hendricks, Business Official
DOE Grant No. DE-FG05-94ER81701
Amount: \$74,826

Advanced methods for the conversion of natural gas to liquid fuels are needed so that natural gas energy resources can be better utilized. In recent research breakthroughs, ceramic monoliths have been used in partial oxidation to catalyze very fast, high selectivity synthesis of higher hydrocarbons from methane. Use of metal monoliths (solid metal plates perforated with small, uniform holes) is planned as a new catalyst for carrying out these reactions. Metal monoliths have high thermal conductivity, so that the heat of reaction can be removed and the reaction temperature regulated. This will allow faster reactant feed rates and higher yields than are possible with currently available ceramic monolith catalysts. A novel fabrication technique allows thin layers of noble metals to be incorporated into the holes of the monolith, so that the reaction rate can be further enhanced. These monoliths can be fabricated with hole diameters less than one micron and porosities as high as 75%. The proposed metal monolith catalysts can be mounted in large arrays, and thus scaled up for commercial chemical production. In Phase I, metal monoliths will be used to examine the oxidation of CH₄ and other components in natural gas to produce synthesis gas and other liquid products. These reaction products can be used as fuels and in various chemical production processes.

Anticipated Results/Potential Commercial Applications as described by the awardee: The metal monolith catalyst technology provides a way to scale up laboratory oxidation reactions for commercial chemical production. Commercial applications include: (1) Replacement for steam reforming of natural gas in methanol synthesis; (2) Production of methanol and synthetic diesel fuels; (3) Generation of hydrogen in chemical plants; (4) Production of higher hydrocarbons to olefins and oxygenated products; (5) Generation of ethylene oxide from ethylene; (6) Production of acrylonitrile from propane; (7) Cleanup of flue gases; (8) Automotive catalytic converters; (9) Cleanup of waste gas streams.

A Membrane Reactor for the Spontaneous Conversion of Natural Gas and Carbon Dioxide Mixtures into Valuable Feedstock--Eltron Research, Inc., 2830 Wilderness Place #E, Boulder, CO 80301; (303) 440-8008

Dr. Michael Schwartz, Principal Investigator
Ms. Eileen E. Sammells, Business Official
DOE Grant No. DE-FG02-94ER81748
Amount: \$74,998

This Phase I project will be directed towards promoting the spontaneous conversion of methane/carbon dioxide mixtures into synthesis gas which will be available for subsequent conversion into methanol. This will be performed across novel mixed ionic (O^{2-}) and electronic conducting perovskite membranes over the temperature range of 600 to 800°C. Membranes will behave as short-circuited electrochemical cells. Compared to current methane steam reforming technology, which is endothermic and requires subsequent composition adjustment prior to the methanol synthesis step, the new technology would be both simple and inherently of low cost. Reformation of methane/carbon dioxide mixtures will rely upon O^{2-} species being continuously generated at an appropriately selected catalyst site on the oxidizing side of the membrane.

Anticipated Results/Potential Commercial Applications as described by the awardee: This research will result in characterizing a mixed conducting membrane technology compatible with the spontaneous conversion of methane/carbon dioxide mixtures to synthesis gas using oxygen conveniently separated from the atmosphere. This would be of significant economic and technical benefit to the Nation by lowering the cost of an important chemical feed stock using an inherently simple process.

Tubular Catalytic Membrane Reactors for the Spontaneous Conversion of Humidified Natural Gas to Synthesis Gas--Eltron Research, Inc., 2830 Wilderness Place #E, Boulder, CO 80301; (303) 440-8008

Dr. Anthony F. Sammells, Principal Investigator
Ms. Eileen E. Sammells, Business Official

DOE Grant No. DE-FG02-94ER81750
Amount: \$74,993

This Phase I investigation is directed towards promoting the spontaneous conversion of humidified natural gas to synthesis gas compatible with subsequent preparation of methanol without any intermediate compositional adjustment being necessary. This will be performed across novel tubular mixed ionic (O^{2-}) and electronic conducting perovskite membranes over the temperature range of 600 to 800°C. Membranes will behave as short circuited electrochemical cells. Compared to current methane steam reforming technology, which is endothermic and requires subsequent composition adjustment prior to the methanol synthesis step, the new technology would be both simple and inherently of low cost. Initial methane activation will rely upon O^{2-} species being continuously generated at an appropriately selected catalyst site on the oxidizing side of the membrane.

Anticipated Results/Potential Commercial Applications as described by the awardee: This research will result in characterizing a tubular catalytic membrane reactor technology compatible with the spontaneous conversion of humidified methane to stoichiometric synthesis gas using oxygen conveniently separated from the atmosphere. This would be of significant economic and technical benefit to the Nation by lowering the cost of an important chemical feed stock using an inherently simple process.

A Multi-Functional Component to Simplify Fuel Cell Power Plants--Energy Research Corporation, 3 Great Pasture Road, Danbury, CT 06813; (203) 792-1460

Mr. Andrew Skok, Principal Investigator
Dr. H. C. Maru, Business Official
DOE Grant No. DE-FG05-94ER81756
Amount: \$74,999

Carbonate fuel cell power plants offer the most efficient and environmentally superior option to generate electricity from natural gas, coal gas, and other hydrocarbon fuels. To realize the greatest commercial potential of these power plants, advances are desirable to improve the system performance and

reduce its overall cost. This project addresses improvements in cost and performance characteristics of the carbonate fuel cell system. It replaces several subsystems by an integrated multi-functional component to reduce overall system cost. The proposed multi-functional system integrates the carbon dioxide (CO₂) management burner system with an oxidant recycle blower, an exhaust fuel booster, and start-up burners. The resulting system will have a minimum number of highly reliable components and a greater operating range. A cost savings of 100 to 150 \$/kW may be realized with this approach. A techno-economic feasibility study is planned to investigate the attractiveness of the concept. During Phase I, a detailed parametric analysis will be performed for several discrete components. This will include the spent fuel burner used in CO₂ management, the hot oxidant recycle blower, and the start-up burner. Operability of these subsystems in an integrated mode using the planned concept will be examined. Experiments will be performed to verify the feasibility of parameters and integration options using a subscale test facility. During Phase II, a system verification of the multi-functional component in a carbonate fuel cell stack will be performed.

Anticipated Results/Potential Commercial Applications as described by the awardee: The planned concept is anticipated to simplify a carbonate fuel cell power plant and improve its operability. A significant reduction of up to 100 to 150 \$/kW in the system cost is anticipated. The carbonate fuel cell power plants, due to their outstanding thermal efficiency and environmentally superior characteristics, are expected to become a significant energy conversion option by the turn of the century. This concept will improve the commercial potential of carbonate fuel cell power plants, and offer an exceptional opportunity for providing economically competitive, high efficiency, low emissions power generators for utilities and industrial and commercial cogenerators. The concept, once developed, may also be used in solid oxide and phosphoric acid fuel cell power plants.

Cost Effective Stimulation of Shallow Gas Wells Using High Energy Gas Fracturing Fielded Without a Wireline or Workover Rig--J Integral Engineering, 165 Southwest Tualatin Loop, West Linn, OR 97068; (503) 557-1370
Dr. Richard A. Schmidt, Principal Investigator
Dr. Richard A. Schmidt, Business Official
DOE Grant No. DE-FG03-94ER81791
Amount: \$74,832

Current models and data show that High Energy Gas Fracturing (HEGF) has great potential as a stimulation tool in shallow gas storage wells. In these wells the in situ stresses are sufficiently low for the process to generate adequate gas volumes and to create an effective multiple fracture network. To address this opportunity, HEGF fielding techniques must be simplified and costs reduced to provide a relatively low cost alternative treatment method that can restore deliverability without resorting to chemical treatment, hydraulic fracturing, or the drilling of new wells. The HEGF tool will be redesigned using a proprietary concept that will eliminate the need for wireline, slick line, tubing, or any other support equipment. It will also eliminate the problem of wireline damage so often experienced in HEGF treatments. Stimulation needs of shallow gas wells will be reviewed on technical and economic grounds to determine the degree of fracturing required in these wells. Existing HEGF models and data will be used to design a prototype treatment that meets these fracturing requirements. A single prototype treatment will be conducted with the new device in Phase I, and sufficient pre-test and post-test diagnostics and analyses will be conducted to provide inputs to the work plan for Phase II.

Anticipated Results/Potential Commercial Applications as described by the awardee: Successful design and testing of the improved HEGF device should lead to additional field tests in Phase II. Improved HEGF models, tested against a controlled data base, should optimize the process for shallow gas storage wells and improve the design of multiple fracture treatments in general. Phase III should commercialize the device and could provide the oil and gas industry with a new, cost effective stimulation technique.

Development of a Higher Pressure Rotary Blowout Preventer for Safe Directional Drilling in Underbalanced Applications--Kalsi Engineering, Inc., 745 Park Two Drive, Sugar Land, TX 77478; (713) 240-6500

Dr. M. S. Kalsi, Principal Investigator

Dr. M. S. Kalsi, Business Official

DOE Grant No. DE-FG03-94ER81796

Amount: \$75,000

This project is aimed at the development of a new generation of rotary blowout preventers capable of safe, reliable, and cost effective handling of the high pressures expected in underbalanced horizontal and directional drilling applications. Pressures of up to 5,000 psi (or even higher) can be expected when drilling with air, foam, or nitrified mud in the low permeability formations in the U.S. (e.g., Greater Green River Basin) that have large amounts of recoverable natural gas. Attaining the goal of safely and economically recovering gas from these vast reservoirs by underbalanced drilling has been hampered by the lack of a suitable high pressure rotary shaft seal. Recent technological developments relating to a novel hydro-dynamically lubricated rotary shaft seal and a floating seal carrier have increased the pressure goal limits of rotary blowout preventers from 700 psi to 2,000 psi. To meet the high pressure goal of 5,000 psi, Phase I outlines a systematic technical development effort that includes a combination of innovative improvements, rigorous analysis, and testing of the high pressure rotary seal concept. Successful completion of Phases I and II will result in the development of an advanced technology 5,000 psi rotary preventer which has the potential of significantly reducing the cost of recovering natural gas in an environmentally acceptable, safe, and reliable manner.

Anticipated Results/Potential Commercial Applications as described by the awardee: Successful completion of this project will result in an advanced technology high pressure and rotary blowout preventer. The new design will be capable of providing reliable, safe, and cost effective operation at pressures of up to 5,000 psi.

Membrane Module Development for a Natural Gas Dehydration Process--Membrane Technology and Research, Inc., 1360 Willow Road, Suite 103, Menlo Park, CA 94025; (415) 328-2228

Dr. Hans Wijmans, Principal Investigator

Ms. E. G. Weiss, Business Official

DOE Grant No. DE-FG03-94ER81807

Amount: \$75,000

Virtually all natural gas must be dehydrated before entering the pipeline. Currently, glycol absorption dehydrators are widely used. However, these units coextract benzene, a known carcinogen, and release the benzene to the atmosphere. In addition, glycol dehydrators are not well suited for use on small gas streams or on offshore platforms, increasingly common sources of natural gas. Membrane processes are an alternative approach to natural gas dehydration. The costs are likely to be comparable to those of the glycol process for low throughput applications, but benzene emissions are eliminated. The suitability of the membrane process for use on isolated small gas streams and on offshore platforms is an advantage likely to encourage industry use. Membranes with the required selectivity and flux for a technically viable membrane dehydration process have already been identified. Small modules incorporating these membranes successfully dehydrate synthetic natural gas at pressures up to 950 psig. However, the membrane module design must be significantly improved to reduce or eliminate concentration polarization effects. Concentration polarization arises from the formation of a stagnant gas layer adjacent to the membrane, and decreases the module separation performance below acceptable levels. In Phase I, the module design will be optimized to mitigate the effects of concentration polarization and to maximize the separation achieved. In Phase II, the process will be scaled up to the pilot demonstration scale. A four-module pilot system will be constructed and equipped with commercial-scale modules. The ability of the system to dehydrate natural gas streams will be evaluated over a period of 3-6 months. Preliminary offers for Phase II field sites have been obtained from both a major gas field operator and a supplier of gas processing equipment.

Anticipated Results/Potential Commercial Applications as described by the awardee: A simple,

efficient membrane process for the dehydration of natural gas would be competitive with conventional glycol and molecular sieve dehydration systems. The modular nature of membrane systems would make dehydration of small streams economically feasible. The absence of direct-fired reboilers and the reduced size and weight of the membrane systems are operational advantages, especially for off-shore gas production platforms.

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Separation of Nitrogen from Natural Gas Using Novel Membranes and Membrane Processes-- Membrane Technology and Research, Inc., 1360 Willow Road, Suite 103, Menlo Park, CA 94025; (415) 328-2228

Dr. Kaaeid Lokhandwala, Principal Investigator
Ms. E. G. Weiss, Business Official
DOE Grant No. DE-FG03-94ER81809
Amount: \$75,000

Thirteen percent of known U.S. gas reserves, containing more than 4% nitrogen, cannot be exploited because no economical technology for removing the nitrogen exists. Membrane processes could make this gas available if membranes with a methane/nitrogen selectivity of 6 or more were available; A number of materials that are within the range of this selectivity have been developed. One polymer has a selectivity of 5.5, the highest polymer membrane methane/nitrogen selectivity known. These methane-permeable membranes will be incorporated into an innovative process that separates the raw gas into three streams: a product gas stream containing less than 4% nitrogen at pipeline pressure; a condensed, higher hydrocarbon (greater than 3 carbons) stream, which has more value as a liquid chemical feedstock than as a gaseous fuel; and a waste, nitrogen-rich gas stream, which is used to power the process and for other on-site fuel use. The cost of producing pipeline gas by the process is estimated to be \$0.55/thousand standard cubic feet for a 1 million cubic feet per day plant, which is very competitive with alternative technologies. In the Phase I program, the new membrane materials will be evaluated, and the optimum material will be selected for scale-up in Phase II. The tests will provide data on the effect of temperature on the methane fluxes and methane/nitrogen selectivities. These data will then

be used to perform a technical and economic feasibility analysis of a process that incorporates the membranes into an energy-efficient separation scheme that also recovers natural gas liquids. If the results are sufficiently encouraging, a skid-mounted proof-of-concept system will be constructed in Phase II for evaluation in the laboratory and in a small-scale field test.

Anticipated Results/Potential Commercial Applications as described by the awardee: If successfully developed, this process would allow low-quality natural gas from several large known, but currently unexploited, fields to be processed economically to pipeline specifications.

88

Continuous Pressure Swing Adsorption (CPSA) for Nitrogen Rejection from Natural Gas-- Northwest Fuel Development, Inc., 4064 Orchard Drive, Lake Oswego, OR 97035; (503) 699-9836
Dr. Peet M. Soot, Principal Investigator
Dr. Peet M. Soot, Business Official
DOE Grant No. DE-FG03-94ER81819
Amount: \$75,000

A continuous pressure swing adsorption (CPSA) process will be developed in Phase I for nitrogen rejection from low quality natural gas. This process will remove the sole techno-economic hurdle for utilizing major resources of low quality natural gas. This will provide a methodology for producing a valuable fuel resource out of gas resources which are currently either being thrown away or are left unused in the geologic formations in which they were discovered. The CPSA process takes the batch operating conditions of traditional PSA and yields a continuous system. The reduction of vessels and simplification of process operation yield significant economic advantages over batch PSA. The planned research should lead to the identification of process parameters which will be the basis for patent submittals. The fundamental concept of continuous rapid cycling PSA has been proven in the laboratory for different product objectives. This CPSA research can build on prior work to rapidly develop a commercial nitrogen rejection process.

Anticipated Results/Potential Commercial Applications as described by the awardee: A

significant fraction of the Nation's gas reserves are of low quality. This is a resource of over 100 trillion cubic feet of natural gas. It could solely provide the entire Nation's domestic natural gas production for up to 10 years. This nitrogen rejection process also provides economic and environmental benefits. It is economically competitive, and it will capture and use the methane (a greenhouse gas) emissions which are now going into the air from coal mines.

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Forecasting Reservoir Thickness with Fractals--
NW Resources, P.O. Box 187, Socorro, NM 87801;
(505) 835-5220

Mr. Trent Boneau, Principal Investigator

Mr. Bill Weiss, Business Official

DOE Grant No. DE-FG05-94ER81821

Amount: \$75,000

The Nation desires to expand the use of clean burning, competitively priced natural gas. The increased demand for natural gas has prompted new drilling in established gas fields. The proper placement of the new wells is dependent on the gas formation properties between the existing wells. One of the properties is the thickness of the gas bearing zone. It is generally accepted that the formation thickness between wells in natural gas reservoirs can be satisfactorily estimated with current technology. Unfortunately, current methods of estimating thickness such as isopach maps based on experience, judgement, and intuition have proven ineffective in predicting the formation thickness encountered by infill wells drilled in a gas reservoir. The infill wells were drilled in a one township area which encompassed 115 prior wells. Six wells cut a cumulative of 187 feet of gas producing formation where 320 feet were anticipated. The 200-acre well spacing did not provide the small scale information required to accurately estimate the interwell thickness. Fractal geometry is a new mathematical tool that has application in solving the small scale data problem. Fractals are based on the recurring nature of natural systems at various scales. The fractal properties determined from the large scale, areal variation in thickness measured at the existing wells will be used to predict the interwell (small scale) thickness at the infill drill sites. The objective of Phase I is to develop a predictive tool, based on fractal geometry, that will generate estimates of

interwell thickness. The actual thickness measured at the existing wells in the reservoir will be a condition of the fractal estimates.

Anticipated Results/Potential Commercial Applications as described by the awardee: The completed research will be especially useful to petroleum technicians charged with expanding production from natural gas fields. The planned method, using field data other than thickness, could be used to predict the areal distribution of permeability, porosity, fractures, and faults. A successful conclusion of the research would be commercial software that can be used to improve the selection of infill drilling locations in heterogeneous natural gas fields.

90

Redesign of Ammonia Absorption Refrigeration Units for Low Temperature Applications in Natural Gas Processing--Process Technology, Inc.,
14811 St. Mary's Lane, Suite 165, Houston, TX 77079; (713) 493-4116

Mr. Jack Wiewall, Principal Investigator

Mr. J. R. Wiewall, Business Official

DOE Grant No. DE-FG05-94ER81833

Amount: \$75,000

Gas transmission pipelines require natural gas delivered to them to meet a hydrocarbon (HC) dewpoint specification in order that the HC liquids are not dropped out in the line during transmission. Similar specifications are imposed by plant operators on the fuel gas that is consumed by their machinery. A market exists for an economical ammonia (NH₃) absorption unit to replace compression units utilizing freon that will produce refrigeration at temperatures in the range of -10° to -15° F. Existing commercially available air cooled NH₃ absorption refrigeration units are designed and manufactured to produce refrigeration in the 40 to 44°F range with ambient air temperatures ranging from 20 to 100°F. The NH₃ units are sealed units utilizing simple low cost mechanical devices to regulate the process flow. To extend the temperature range down to -15°F utilizing simple low cost controls will require some innovative control technology, component modification, and testing under varying load and ambient conditions. A test unit now operates at 20°F. The next step will require different controls and redesign of the unit

components to achieve the lower temperatures. The objective of Phase I is to build testing facilities, provide a sophisticated variable control and monitoring system, do a detailed evaluation of the components in the unit, and do a preliminary evaluation of a new, low cost control system.

Anticipated Results/Potential Commercial Applications as described by the awardee: A low temperature unit would serve a market that currently exists for trouble free, low temperature chillers to chill natural gas to -15°F. This would a) allow production of good lean fuel gas, b) process small volumes of natural gas to produce liquid petroleum gases in older fields, c) replace compression units using freon and d) meet transmission line HC dewpoint specifications.

91

Systematic Mapping of Natural Fractures to Predict Coalbed Methane Production--Sage Discovery, Inc., 345 Market Street, P.O. Box 882, Meeker, CO 81641-0882; (303) 878-5160
Mr. Bruce E. Barnum, Principal Investigator
Ms. Jackie R. Barnum, Business Official
DOE Grant No. DE-FG03-94ER81851
Amount: \$75,000

Reliable mapping of natural fracture systems existing in coal beds is the key to efficient development of the large volume coalbed methane resources in-place in the Piceance Basin located in northwest Colorado. Adequate permeability to support commercial production requires the presence of a well developed coal cleat system. In Phase I innovative evaluation methodology will integrate detailed direct coal cleat measurements, indirect indicators of cleat intensity, and geophysical interpretations with trend control from area structure and stratigraphy to produce maps delineating the pattern of coal cleat intensity and orientation. Distribution and relative importance of local reservoir permeability heterogeneities will also be evaluated. The study area on the north margin of the Piceance Basin includes approximately 25 recently completed coalbed methane wells which will provide production data to directly test and calibrate the maps for prediction of coalbed methane recoverability. If testing proves the utility of this recoverability evaluation, a significant level of true

innovation will be achieved. New technology will provide knowledge essential for efficient recovery of this desirable resource, opening new opportunities for extensive resource development, and defining significant new U.S. clean energy reserves.

Anticipated Results/Potential Commercial Applications as described by the awardee: This evaluation is expected to produce maps rapidly and cost-effectively which provide a guide to efficient development of this important resource which is presently unavailable. Systematic application of this technology in Phases II and III to larger areas and other U.S. coal fields can be expected to result in significant profit opportunities for gas producers and new clean, domestic energy supplies.

92

Removal of Hydrogen Sulfide from Natural Gas by Electron Beam Irradiation--Science Research Laboratory, Inc., 15 Ward Street, Somerville, MA 02143; (617) 547-1122
Dr. Henry Eppich, Principal Investigator
Dr. Jonah Jacob, Business Official
DOE Grant No. DE-FG02-94ER81853
Amount: \$74,972

Natural gas represents 20% of the primary energy resources of the United States and accounts for almost half the energy consumed for residential heating. 22% of the natural gas reserves in this Nation are not usable because they contain more than 4 ppm of hydrogen sulfide (H₂S). This corresponds to 19 trillion cubic feet of the known reserves. It is projected that 80 trillion cubic feet of the undiscovered natural gas resources are also contaminated with unacceptable concentrations of H₂S. Natural gas contaminated with H₂S is an environmental hazard due to the toxicity of H₂S in the gas itself and the sulfur-containing compounds produced and released during combustion. In addition, it is corrosive to pipeline systems. Current technologies for H₂S removal are complex and cost between 20 and 26 cents per million standard cubic feet. This cost is independent of the concentration of H₂S. The cost of the electron beam process, based on all-solid-state accelerators, is 6 cents per million standard cubic feet for natural gas containing 1000 ppm H₂S. The cost for the electron beam process decreases to 0.6 cents per million for natural gas

containing only 100 ppm. Approximately 4.3 trillion cubic feet of the natural gas reserves contain <100 ppm H_2S and 8.6 trillion cubic feet contain <1000 ppm H_2S . In Phase I the efficiency of H_2S removal from natural gas by electron beam irradiation will be determined. These proof-of-principle experiments will be performed on an existing all-solid-state linear induction accelerator. Based on the data from these experiments, Phase II demonstration experiments will be designed and conducted to determine the technical and economic viability of using electron beam irradiation to remove H_2S in a flowing natural gas pipeline system.

Anticipated Results/Potential Commercial Applications as described by the awardee: There exist 19 trillion cubic feet of known natural gas reserves that are not usable because of contamination by H_2S . Should this concept of electron beam irradiation be a cost effective process for removal of the H_2S , this process will be commercialized in Phase III. The electron beam technology has other applications including control of stack gas emissions, bulk sterilization of disposable medical products, and clean-up of contaminated water.

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Sulfur Recovery from Hydrogen Sulfide-Prone Natural Gas--Science Research Laboratory, Inc., 15 Ward Street, Somerville, MA 02143; (617) 547-1122
Dr. Henry Eppich, Principal Investigator
Dr. Jonah Jacob, Business Official
DOE Grant No. DE-FG02-94ER81856
Amount: \$74,943

Natural gas contaminated with hydrogen sulfide (H_2S) is an environmental hazard, corrosive to natural gas distribution systems; it prohibits direct use of 19 trillion cubic feet of known natural gas reserves and 80 trillion cubic feet of undiscovered reserves. Current technologies for H_2S removal are too complex and costly. In a separate grant application, it was suggested that an electron beam process will remove H_2S from natural gas at one-third the cost of competing technologies. The electron beam process for removal of H_2S , however, decomposes it into hydrogen and elemental sulfur particulates in the size range 0.5 to 1.5 μm . Very

few separation technologies efficiently remove submicron particles from gas phase flows. In this project an innovative concept, known as a Confined Vortex Scrubber, which has demonstrated 98% separation of 0.3 μm particles in air at standard conditions will be investigated. The Confined Vortex Scrubber consists of a cylindrical vortex chamber with multiple tangential process gas inlet jets. The scrubbing liquid is confined to the outer vortex chamber wall because of high radial accelerations causing small bubbles whose micro-cyclonic action is responsible for the very effective separation of submicron particles. In Phase I it will be demonstrated, via bench-top scale tests, whether the Confined Vortex Scrubber produces high submicron separation efficiencies under the much more dense conditions typical of natural gas gathering systems. These data plus scaling relations developed in Phase I will be used to design a scaled-up Confined Vortex Scrubber for Phase II feasibility tests. The Phase II project will provide the necessary scaling data and relations for carrying this technology to commercialization.

Anticipated Results/Potential Commercial Applications as described by the awardee: There exist 19 trillion cubic feet of known natural gas reserves that are not usable because of contamination by H_2S . Should the concept of electron beam irradiation/Confined Vortex Scrubber sulfur recovery be a cost effective integrated process for removal of the H_2S from natural gas, then it will be commercialized in Phase III. The electron beam and/or Confined Vortex Scrubber technology have other applications including control of stack gas emissions, bulk sterilization of disposable medical products, and clean-up of contaminated water.

COAL-BASED POWER SYSTEMS TECHNOLOGY

94

High Temperature Brazing of Silicon Carbide--

Busek Company, Inc., 19 Kearney Road, Needham, MA 02194; (617) 449-3929

Dr. V. Hruby, Principal Investigator

Mrs. J. Budny, Business Official

DOE Grant No. DE-FG02-94ER81721

Amount: \$74,492

The development of high performance ceramics such as silicon carbide (SiC) and silicon nitride (Si_3N_4) has progressed to the point where high temperature (~ 2000°F), highly stressed structural components operating in hostile environments can be considered. However, the technology to join such components to each other or to metals capable of high temperature operation is lacking and impedes their rapid progress into such applications as internal combustion engines, turbines, and heat exchangers. An example is the high temperature air furnace heat exchanger that has SiC as its primary tube candidate and requires a multitude of reliable gas tight joints operating at 1800°F. Therefore, this project will develop a high temperature brazed joint between SiC and a superalloy suitable for the demanding service. In Phase I, a group of test pieces will be designed and fabricated using three different filler metals and four different insert metals to accommodate induced stresses arising from difference in thermal expansion characteristics. The test pieces will undergo thorough metallographical examination and shear stress testing to determine the optimal configuration. Based on the results, a SiC tube-to-metal tube joint will be designed. In Phase II, additional test pieces will be fabricated and strength tested at 1000 and 1800°F. The tube joints designed in Phase I will be fabricated and tested at 1800°F in an oxidizing atmosphere.

Anticipated Results/Potential Commercial Applications as described by the awardee: A reliable high strength, high temperature SiC-to-metal brazed joint will find applications in many technological areas. The primary area includes energy conversion devices ranging from automotive engines to those typically found in fossil fueled plants and fusion reactors where SiC is an ideal material for the first

wall. The efficiency gains realizable by the use of SiC components amply justify the planned development.

95

A Highly Efficient Two Stage Ceramic Foam Burner for Clean Combustion of Low BTU Coal

Gas--Selee Corporation, 700 Shepherd Street, Hendersonville, NC 28792; (704) 697-2411

Dr. Chi-Li Lin, Principal Investigator

Mr. Kenneth R. Butcher, Business Official

DOE Grant No. DE-FG05-94ER81860

Amount: \$75,000

A highly efficient two stage porous media combustor is planned which will allow clean combustion of low BTU coal gas. Experiments in Phase I will demonstrate the technical and economic feasibility of the technology. Several porous media which are suitable for this application will be investigated in detail. The combustor design and optimum operation parameters will also be developed. Based on the technology developed in Phase I, improved porous media and combustor designs as well as scaled up synthesis processes will be completed in Phase II. The pilot tests in Phase II will be designed for future commercial production and applications. Future marketing and manufacturing plans will also be established in Phase II.

Anticipated Results/Potential Commercial Applications as described by the awardee: It is anticipated that porous media will enhance the efficiency of low BTU coal gas combustion. Lower pollutant emissions are also expected with this two stage porous media combustor design. The desired properties of porous media will be investigated in the Phase I project. It is also expected that the Phase I results will demonstrate the economic advantage of using the two stage porous media burners for combustion of low BTU coal gas. The pilot tests in Phase II will prove the feasibility for future commercialization of the products and processes.

A Long Life Zinc-Oxide-Titanium-Oxide Sorbent--TDA Research, Inc., 12345 West 52nd Avenue, Wheat Ridge, CO 80033; (303) 940-2301
 Dr. Robert J. Copeland, Principal Investigator
 Mr. Michael E. Karpuk, Business Official
 DOE Grant No. DE-FG03-94ER81881
 Amount: \$75,000

Coal-fired gasifier combined cycles (GCC) have both high efficiency and very low emissions. A critical need for GCCs is a method of removing the hydrogen sulfide (H_2S) produced from the sulfur in the coal from the hot gases. There has been extensive research on hot gas clean-up systems, focused on the use of a zinc oxide based sorbent (e.g., zinc titanate). Unfortunately, current sorbents can be used for only a few cycles before they either lose their activity or fall apart. A new method has been developed for producing sorbent pellets with greatly increased

lifetimes. When used with a tin oxide sorbent, the pellets produced by the new methods have an estimated average lifetime of over 200 cycles under hot gas cleanup conditions. These improved fabrication methods should be directly applicable to the production of long life, low cost sorbents containing zinc oxide. The Phase I project aims to demonstrate that the process can be adapted to the leading sorbent (ZnO), optimize the sorbent composition, and measure cyclic life.

Anticipated Results/Potential Commercial Applications as described by the awardee: This new method of producing the sorbent will reduce the cost of hot gas cleanup of H_2S by increasing the life and decreasing the cost of the zinc oxide sorbent. The new method may be applicable to other absorbent applications. The low cost, long life sorbent will reduce the cost of hot gas cleanup H_2S sorbents and improve the economics of GCC.

ENHANCED OIL RECOVERY

A High Performance Wellbore Logging Tool Using Fiber Optic Gyro Technology--Optiphase, Inc., 7652 Haskell Avenue, Van Nuys, CA 91406-2005; (818) 782-0997
 Mr. Ira J. Bush, Principal Investigator
 Mr. Ira J. Bush, Business Official
 DOE Grant No. DE-FG03-94ER81824
 Amount: \$75,000

Current state-of-the-art wellbore logging systems have been applied effectively to measure shallow vertical wells. These systems however become error prone when the wellbore inclination approaches the earth's rotation axis or approaches an orthogonal direction to earth's gravity. Additionally, when these systems are required to operate at temperatures greater than $100^\circ C$, they must be fitted with a rechargeable cooling system which impedes the measurement process and limits down hole measurement time. All of these problems are attributable to the measurement ability and limited operational temperature range of the logging instrument's spinning wheel gyros. This project

involves an innovative approach to a wellbore logging instrument which eliminates the problems associated with the conventional loggers. This approach involves the use of low cost, solid state fiber optic strapdown gyros in a 3-axis measurement configuration enabling logging operations to 25,000 feet or more, operational temperature range to $200^\circ C$ with indefinite operation times, accurate measurements independent of wellbore orientation, and elimination of all active down hole gyro electronics. Phase I will conduct a design analysis of the proposed fiber optic gyro concept, develop a single axis demonstration model, and conduct laboratory environmental testing to verify high performance measurement capability at temperatures up to $200^\circ C$. In Phase II a wellbore logging tool will be developed incorporating the proposed fiber gyros, and it will be field tested.

Anticipated Results/Potential Commercial Applications as described by the awardee: This new approach offers significant improvements over existing well logging systems and will become an important tool in the enhancement of oil recovery world wide.

A Practical High Resolution Petrographic Imaging System for Assessing Reservoir Quality--Terra Tek, Inc., 420 Wakara Way, Salt Lake City, UT 84108; (801) 584-2430

Dr. Lawrence B. Owen, Principal Investigator
Ms. Jean Jensen, Business Official
DOE Grant No. DE-FG03-94ER81886
Amount: \$75,000

Drill cuttings represent a huge source of valuable data bearing on reservoir quality issues. Cuttings are produced during the drilling of every oil and gas well. However, technological innovations are lacking that would allow these materials to be utilized for assessing storage and transport properties such as effective porosity, permeability, electrical properties, capillary pressure characteristics, and geologic properties like fracture distribution, permeable pathways, and diagenetic alteration. Conventional coring and core analysis can be used to supplement well logging, but the cost of these operations and the risks that are sometimes entailed in coring deep and highly deviated wells often preclude collection of valuable reservoir quality data. The Phase I program couples an ultra-high resolution imaging technology called confocal scanning laser microscopy with state-of-the-art image analysis capabilities to form an analysis capability for direct estimation of important transport and reservoir quality parameters. The objective is to apply this new integrated technology to drill cuttings. The method can also be applied to sidewall cores, which often can

not be characterized by conventional core analysis techniques owing to size constraints and the condition of specific samples which may be damaged during recovery. It has been found that intrinsic 3-D properties of porous networks, such as tortuosity, can be directly mapped by confocal microscopy permitting application of Kozeny-Carmen relationships for calculation of transport properties without over-reliance on geometric approximations. Demonstrated capillary pressure curve correlations can also be usefully applied to estimate permeability by using image analysis methods to measure the pore size distribution of samples. Biases introduced by sample surface roughness, vertical heterogeneity, and artifacts of image processing for pore separation can be eliminated by use of the optical sectioning of confocal microscopes.

Anticipated Results/Potential Commercial Applications as described by the awardee: The Phase I program will generate cuttings and sidewall core analytical protocols that will support accurate, rapid, and highly cost-effective assessment of reservoir quality factors including permeability, total porosity, effective porosity, formation factor, pore size distribution, capillary pressure response, as well as details of the permeable pathways, fracture distributions, and the impact of diagenesis on fluid storage and migration. Successful demonstration of the application of this technology will lead to a commercialization effort where the developed technology will be packaged for routine use by industry.

ROBOTS FOR NUCLEAR ENVIRONMENTS

Interface Designs for Telepresence and Remote Sensing Systems Using Non-Immersive Virtual Reality--Reveo, Inc., 8 Skyline Drive, Hawthorne, NY 10532; (914) 345-9555

Mr. John E. Williamson, Principal Investigator
Dr. Sadeg M. Faris, Business Official
DOE Grant No. DE-FG02-94ER81848
Amount: \$74,314

Telepresence and remote sensing systems have begun to incorporate aspects of the technologies commonly called "virtual reality." This has occurred even though there have been only a few attempts to design these systems using human factors and a solid foundation in cognitive and perceptual psychology. This has resulted in systems with non-intuitive interfaces that are difficult to use. This project will advance the design of these systems using stereoscopic three dimensional (3D) displays, alternative input devices, and interface designs for

non-immersive virtual reality. Traditionally, virtual reality has required the user to wear a Helmet Mounted Display (HMD) and glove. This project will treat the fact that HMDs and gloves cause more problems than they solve. Through the use of current technology, affordable, portable, high quality stereoscopic 3D images that are compatible with existing video infrastructure are possible. The system under development can integrate stereoscopic images from computer graphics packages as well as live video. The three, large stereoscopic 3D screens planned for Phase I provide a wider field of view and higher resolution at lower cost. Furthermore, this design will allow multiple users and the ability to interact unencumbered with both the projected image and other users.

Anticipated Results/Potential Commercial Applications as described by the awardee: Commercial applications include better graphical interface designs with non-immersive virtual worlds, telepresence, and complex skill acquisition. These data and resulting hardware and software designs will directly effect the design of such applications as entertainment, simulation, medical imagery, scientific visualization, air traffic control, remote sensing, and teleconferencing.

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An Innovative Dextrous Hand Exoskeleton--
 Ross-Hime Designs, Inc., 1313 Fifth Street,
 Southeast, Minneapolis, MN 55414; (612) 379-3808
 Mr. Mark Elling Rosheim, Principal Investigator
 Mr. Mark Elling Rosheim, Business Official
 DOE Grant No. DE-FG02-94ER81850
 Amount: \$75,000

DOE requires quality sensory feedback from robot to operator: fine manipulation achieved through robotic hands controlled by human-sized hand exoskeletons. These simplify and make control more intuitive when compared to keyboard or joystick control. Force feedback to these small exoskeletons requires small volume, high efficiency, semi-linear actuator mechanisms. These actuators provide human range, force, and velocity feedback to exoskeleton systems used by operators of dextrous manipulators. The design and construction of a 12-axis dextrous hand exoskeleton (DHE) is being investigated in Phase I. The DHE utilizes revolutionary force reflecting linear

actuator technology and a break-through in mechanical joint technology. The application of actuator reinforced elastomer laminates replicates the flexibility of muscles and tissues in humans. The use of piezoelectric surface actuator arrays in the hand will be investigated as a method to provide a delicate sense of touch critical for detecting slippage of workpieces.

Anticipated Results/Potential Commercial Applications as described by the awardee: Prosthetics, medical speciality of physical medicine, and rehabilitation fields could utilize this technology. Control of robots, Disney-type animatronic figures, and virtual reality environments would also be enhanced.

101

A Low Cost Infrared Sensor Based System for Robotic Welding--Weld Technology, Inc., 8204 Gondola Drive, Orlando, FL 32809; (205) 887-5886
 Mr. Wing Y. Chin, Principal Investigator
 Mrs. Teresa S. Chin, Business Official
 DOE Grant No. DE-FG05-94ER81899
 Amount: \$74,993

Nondestructive testing, identification, and repair of weld defects have been documented to consume as much as 25% of the total weld production cost in pipelines, ship fabrication, and power generating systems. Infrared sensor controlled welding systems have been demonstrated that would greatly reduce or eliminate expensive, after-the-fact nondestructive testing and weld repair. However, the cost of these systems has been well over \$60,000, and hence commercialization of this technology has not occurred. This project will develop an infrared sensor-based system for weld process control that is nearly an order of magnitude cheaper than current systems. This cost would place this new technology well within the reach of pipeline, ship, and heat transfer piping fabricators. The large cost reduction is due to development of a new low cost infrared sensor head. In Phase I, prototype sensor heads will be constructed and tested to demonstrate the ability of the new system to identify weld perturbations which occur during commercial, large scale welding operations. The ability of the infrared sensors to identify varying depths of weld penetration and weld microstructure (mechanical properties) will be tested.

Sensor system sensitivity, response, and robustness will be examined to determine the applicability of the device to controlling the welding process in a harsh welding environment. Based upon the successful testing of the sensor system, Phase II research will lead to the development of a prototype infrared sensor-based control system for robotic welding.

Anticipated Results/Potential Commercial Applications as described by the awardee: This low

cost, infrared sensor-based weld control system will greatly improve the quality and productivity of the welding process by enabling in-process control of weld penetration depth, microstructure formation, torch position, and fixturing errors. Significant decreases in costs of weld production, nondestructive examination, and weld rework are anticipated for construction and repair of nuclear and fossil energy piping, oil and gas pipelines, double hull oil tanker ships, and storage vessels.

TECHNOLOGY FOR SPACE NUCLEAR PROPULSION AND POWER

102

An Infrared Bandpass Thermophotovoltaic Filter Production Process--EDTEK, Inc., 14704 Southeast 100th Street, Renton, WA 98059; (206) 235-5163

Mr. William E. Horne, Principal Investigator

Mr. William E. Horne, Business Official

DOE Grant No. DE-FG03-94ER81742

Amount: \$74,962

The conversion of infrared (IR) energy by means of photovoltaic cells, known as thermophotovoltaics (TPV), was suggested in the early 1970s and has been researched by many workers since then. The recent developments of low-bandgap photovoltaic cells and IR bandpass filters have finally made the promise of high efficiency thermophotovoltaic energy conversion a reality. This project seeks to develop a low-cost means of producing the large areas of the IR bandpass filters required for thermophotovoltaic applications. Preliminary analyses of the proposed production process indicate that the filters may be produced for as little as twenty five cents per square centimeter. Using these low cost filters, thermophotovoltaic systems could economically reach efficiencies in excess of twenty percent with IR source temperatures as low as one thousand degrees centigrade. Phase I will address the feasibility of the production process for the filters.

Anticipated Results/Potential Commercial Applications as described by the awardee: The results of the proposed effort will be a low-cost high-volume production process for IR bandpass TPV

filters, raising the efficiency of TPV conversion substantially. Applications are expected in radio-isotope, nuclear, solar, and gas-fired electric powered generators. The applications range from powering deep space probes to nuclear submarines to consumer recreational vehicles.

103

High Temperature Thermally Stable Multi-Layer Quantum Well Films--Hi-Z Technology, Inc., 6373 Nancy Ridge Drive, San Diego, CA 92121-2247; (619) 535-9343

Mr. Norbert B. Elsner, Principal Investigator

Mr. Norbert B. Elsner, Business Official

DOE Grant No. DE-FG03-94ER81777

Amount: \$75,000

An attempt will be made to fabricate multi-layer quantum well films (ML-QWFs) that should have an exceptionally high figure of merit (Z) from materials that exhibit very low diffusion rates. Such materials prevent the quantum well and barrier materials from interdiffusing, thereby degrading the multilayer nanostructure responsible for the improved performance. The improved performance believed to be possible with such materials is due to the confined motion of the charge carriers and the two dimensional quantum well which is in contrast to their three dimensional motion in comparable bulk materials. The layering may also decrease the thermal conductivity. The goal of this effort is to develop ML-QWFs that can operate up to 1100°C for >10 years. Parameters such as layer thickness,

residual strain in the layers, and type of crystal structure will all be considered in the selection of the quantum well and barrier materials. During Phase I various boride alloys will be alternately deposited into quantum layers and their thermoelectric properties characterized.

Anticipated Results/Potential Commercial Applications as described by the awardee: ML-QWFs with a $Z > 1.5$ will be developed that should exhibit very stable thermoelectric properties at elevated temperatures. This ultra thin film technology will allow thermoelectric devices to achieve much higher efficiencies (more than the 17% increase that is requested) and spur the low cost recovery of waste heat.

104

Nuclear Power Feasibility for Near Term Commercial Applications on the Lunar Surface--

International Space Enterprises, 4909 Murphy Canyon Road, San Diego, CA 92123; (619) 637-5777
Mr. Thomas Kessler, Principal Investigator
Mr. Michael Simon, Business Official
DOE Grant No. DE-FG03-94ER81787
Amount: \$75,000

Advanced commercial lunar payloads, scheduled for lunar landing later this decade, require a source of electric power that can provide continuous power at 3 to 40 kilowatts initially, with upgrades to over 100 kW. The power system must be environmentally safe and reasonably priced. Such an integrated power system does not yet exist for lunar surface payloads which experience 14 days of darkness at a temperature of -157°C . However, many building block subsystems, particularly nuclear (from which an integrated system could be constructed) do exist. The planned Phase I study will identify new subsystem requirements, confirm feasibility, and quickly integrate selected subsystems to meet near term commercial customer needs. Results will include conceptual hardware designs, operations concepts, and commercial financing assessment of solutions to the following key technical problems: heat rejection during lunar day and night, site survey and selection to avoid radiation susceptible soils, site preparation for reactor emplacement, physical deployment of a reactor by robotic means, manufacture of radiation shielding in-place, thermal

coupling of radiation shielding with the reactor and surrounding soil, radiation shielding compatible with in-place changes to heat exchanger connections to allow upgrade from direct electric to Stirling cycle, and power transmission methods to fixed and mobile commercial instruments.

Anticipated Results/Potential Commercial Applications as described by the awardee: Advanced lunar surface power represents an enabling technology for scientific and commercial applications that can contribute many millions of dollars to the U.S. economy. Sales of nearly \$900 million are projected from the first seven lunar missions (1997 to 2000). If this initial level of activity is augmented by a significant number of foreign payloads, total sales through 2000 could exceed \$2 billion, not including sales relating to development of payloads.

105

Hydrogen Permeation Barriers for Bimodal Reactors--

Thermacore, Inc., 780 Eden Road, Lancaster, PA 17601; (717) 569-6551
Mr. John R. Hartenstine, Principal Investigator
Mr. Richard W. Longsdorff, Business Official
DOE Grant No. DE-FG05-94ER81888
Amount: \$74,987

Bimodal space nuclear power systems which combine both thermal propulsion and electric power generation capabilities in a single integrated power and propulsion platform have recently emerged as strong candidates for future military and commercial space applications. For propulsion, the reactor heats hydrogen which is exhausted through a nozzle to provide propulsive thrust. Thermal energy from the reactor is also converted to electricity by in-core or out-of-core energy converters. One issue of concern in a bimodal system is the potential for hydrogen permeation into energy conversion components. At bimodal reactor temperatures, hydrogen will permeate through the refractory metal structures degrading the operational capabilities of in-core thermionic converters, or heat pipes used to transmit heat from the reactor to the out-of-core energy converters. This project will develop and demonstrate a hydrogen permeation barrier using a trilayer assembly with a thermally conductive porous powder metal layer between two containment walls. Hydrogen that permeates through the first

containment wall is vented from the porous powder metal to the vacuum of space prior to permeation into critical components. Hydrogen permeation resistant coating will also be evaluated.

Anticipated Results/Potential Commercial Applications as described by the awardee: Successful completion of this program should result in the development of a hydrogen permeation barrier to

protect critical components on space nuclear thermal propulsion and power systems. This technology could be used for Stirling heat engine electric power generators which currently use helium gas. Hydrogen gas can increase the system efficiency. The trilayer assembly could be used as a hydrogen permeation barrier making hydrogen Stirling engines feasible.

TECHNOLOGY TO SUPPORT AND IMPROVE NUCLEAR FUEL CYCLE PROCESSES

106

A Long Life Perovskite Oxygen Electrode for Calcium Oxide Processing in Nuclear Fuel Cycles--Eltron Research, Inc., 2830 Wilderness Place #E, Boulder, CO 80301; (303) 440-8008
Dr. Anthony F. Sammells, Principal Investigator
Ms. Eileen E. Sammells, Business Official
DOE Grant No. DE-FG02-94ER81751
Amount: \$74,997

This project is directed towards developing novel electrocatalysis for oxygen evolution in electrolytic cells used for promoting calcium oxide splitting. The molten salt to be electrolyzed will be contained within a dense, oxygen anion conducting, solid electrolyte tube. The overall technical approach will be systematically pursued in four distinct stages during Phase I as follows: 1) fabricate electrolytic cells, 2) conduct an electrochemical study on both half and full cells, using steady-state, cyclic voltammetry and transient voltage-step current-voltage measurement techniques to gain insight into the performance of selected anodes for oxygen evolution, 3) perform anode electrocatalyst optimization, and 4) fabricate and electrochemically test electrolytic cells for the simultaneous generation of separated calcium and oxygen using optimal experimental conditions.

Anticipated Results/Potential Commercial Applications as described by the awardee: Development of this technology will be expected to provide electrolytic cells incorporating novel oxygen evolution anodes compatible with simultaneous generation of separated calcium and oxygen from

calcium oxide for application in nuclear fuel processing.

107

Oxygen-Evolving Anodes for the Electrolysis of Calcium Oxide--EMEC Consultants, 4221 Roundtop Road, Export, PA 15632; (412) 325-3260
Dr. Rudolf Keller, Principal Investigator
Dr. Rudolf Keller, Business Official
DOE Grant No. DE-FG05-94ER81752
Amount: \$75,000

Electrochemical reduction of calcium oxide is an effective step in the processing of spent nuclear fuels by the Salt Transport Process. It is desirable to conduct this electrolysis with oxygen-evolving anodes, thereby avoiding carbon contamination, but the feasibility of this approach has not yet been established. Three candidate anode materials will be examined for CaO electrolysis in laboratory experiments similar to those previously conducted in other systems. Anode stability shall be established and electrolysis conditions identified at which no chlorine gas forms. It is planned to expand the effort to include the electrolysis of lithium oxide.

Anticipated Results/Potential Commercial Applications as described by the awardee: The project should identify promising anode candidates to improve a process step in the recycling of nuclear fuel. The technology has potential to provide more cost-effective and energy-efficient production of calcium and other metals.

MEASUREMENT OF MECHANICAL PROPERTIES IN CIVILIAN NUCLEAR REACTOR FACILITIES

108

Fracture Toughness Testing with Minimal Material--Packer Engineering, Inc., Plant Component Analysis Division, 200 Fleet Street, Pittsburgh, PA 15220; (412) 921-6441

Dr. James A. Begley, Principal Investigator

Dr. James A. Begley, Business Official

DOE Grant No. DE-FG05-94ER81825

Amount: \$74,811

The feasibility of using minimum sized specimens from broken halves of Charpy specimens to fully characterize the transition range fracture toughness of reactor pressure vessel steels will be evaluated in Phase I. There are well known effects of specimen size on measured fracture toughness values. The use of specimens of minimum size requires accounting for these size effects. This will be done by using a combined constraint/statistical approach to interpreting cleavage fracture toughness measurements. Since substantial plasticity will occur during toughness testing, the J (elastic-plastic) integral parameter will be used to characterize the plastic

stress/strain environment near the crack tip. Differences in constraint (stress triaxiality) as a function of specimen type and size will be treated by computing crack tip plastic stresses and strains and expressing these results in terms of a parameter termed Q . Long crack tip lengths sample more material than short lengths. Sampling size effects will be incorporated by using Weibull weak link statistics. The optimum fracture toughness specimen configuration which can be machined from one half of a broken Charpy specimen will be evaluated by a combined experimental and analytical study. Techniques for automatic machining of this configuration will also be evaluated.

Anticipated Results/Potential Commercial Applications as described by the awardee: Phase I results should provide the basis for a definitive combined analytical and experimental verification of this technique to conduct cleavage range fracture toughness tests with minimal material. It should also provide a basis to develop a fully automated specimen preparation procedure involving minimum waste products.

PERSONAL MONITORING FOR PARTICULATES

109

A Programmable Particulate Sampling System--Anatole J. Sipin Company, Inc., 505 Eighth Avenue, New York, NY 10018; (212) 695-5706

Mr. A. J. Sipin, Principal Investigator

Mr. A. J. Sipin, Business Official

DOE Grant No. DE-FG02-94ER81705

Amount: \$72,400

Personal sampler pumps are worn by industrial workers to determine the concentration of particulates to which the worker has been exposed during a work shift. Usually a particulate collection device, such as a filter, is worn in the breathing zone of the worker and connected to a belt-mounted pump through a flexible tube. This is cumbersome, and

occlusion of the tube can cause an erroneous measurement. Although current pumps maintain a constant air flow rate during sampling for accurate determination of sampled volume, they must be initially set with a flowmeter, and frequent calibrations are required. In Phase I a system will be investigated in which the sampler pump includes a miniature pneumatic pumping unit that has a weight of 4.4 oz and a volume of 8.8 cubic inches. This unit is sufficiently small to be close coupled to the filter in the breathing zone, eliminating problems with flexible filter tubes. The control system used provides an accurate selected flow rate by internal calibration that is stable over a long period. Setting with an external flowmeter or calibrator is unnecessary. A self test feature to check the calibration is also provided. To prevent accidental

interference with operation, or tampering with the pump, sampling valves are externally programmed.

Anticipated Results/Potential Commercial Applications as described by the awardee: This

sampling system should lead to a significant advance in particulate monitoring technique and apparatus. There is a substantial market for an improved dust sampler in industrial applications.

EDUCATIONAL TECHNOLOGY: ELECTRONIC GAME DEVICES FOR MATHEMATICS, SCIENCE, AND ENGINEERING

110

Development of a Computer Game Prototype to Teach Physical Geography--Gautier-Downes and Associates, 2656 Montrose Place, Santa Barbara, CA 93105; (805) 682-8824

Dr. Catherine Gautier, Principal Investigator
Ms. Jeannette Gautier-Downes, Business Official
DOE Grant No. DE-FG03-94ER81770
Amount: \$74,992

There is a presently recognized need for improved geographical science education that can be met by the development of technologically innovative computer games. Therefore, this project will create a prototype adventure computer game (title) based on realistic role playing. It will run on a high performance platform, the 3DO Interactive Multiplayer system developed by Panasonic. The purpose of this project is to teach high school students facts and concepts in physical geography through particular phenomena of importance to the earth system. The planned prototype will be built on El Nino during Phase I of this project. This initial choice of El Nino is guided by previous work done on the development of computer-based educational material. The overall structure would allow the development of other titles that will be added during Phase II which will include monsoons and the exploration of the earth from space. The overall objective is for high school students to learn what El Nino is, how and why it forms, what its impact is, and how it is investigated by playing the scientist's role involved in its study. This will provide students with an introduction to the main disciplines of physical geography: meteorology, oceanography, climatology, and some biology through El Nino causes and effects on weather, sea surface temperature, level of phytoplankton, and fish

population. This project will also introduce the students to some of the new tools used by scientists studying physical geography and El Nino such as remote sensing and numerical/mathematical modeling. Finally, students will learn how major scientific investigations are performed and under what constraints. This project will have different levels of complexity from introductory physical geography (fact-based) to in-depth meteorology and oceanography (concept-based).

Anticipated Results/Potential Commercial Applications as described by the awardee: During Phase I a prototype computer game will be developed and tested. The outcome of Phase II will be the final version of this game that will be marketed to high schools.

111

An Intelligent Tutoring Game to Teach Scientific Reasoning--Research Development Corporation, 2875 Towerview Road, Suite A4, Herndon, VA 22071; (703) 904-1808

Dr. John Leddo, Principal Investigator
Dr. John Leddo, Business Official
DOE Grant No. DE-FG05-94ER81847
Amount: \$75,000

Today's workforce requires ever increasing competence in math, science, and engineering skills. Unfortunately, recent surveys suggest that the U.S. rank at the bottom of industrialized nations in scientific competence of its students. This jeopardizes our long term outlook for leadership in a high tech world. One educational challenge to remedy this is to teach science more the way scientists view it, namely as an evolving process of inquiry, rather than as a

body of facts and "truth" as most people commonly view it. Further, science and math should be taught in an enjoyable context to increase interest. One solution to meet both of these criteria lies in a marriage of intelligent tutoring system (ITS) and electronic game technologies. This project would create an intelligent tutoring game (ITG) to teach the techniques of scientific inquiry that scientists have, while delivering an individualized program of instruction that is both enjoyable and tailored to the specific learning needs of each player. Phase I will be devoted to testing the feasibility of this approach by: (1) defining the topics and skills to be taught, (2) developing an instructional approach, (3) developing an ITG framework, (4) developing a proof-of-concept ITG, (5) evaluating the ITG, and (6) preparing and delivering the final report. Phase II will be devoted to developing and testing a full-scale ITG. Phase III will be devoted to commercializing the Phase II ITG.

Anticipated Results/Potential Commercial Applications as described by the awardee: Potential commercial applications include electronic games to teach scientific reasoning skills that mirror those of scientists. These can be marketed for such systems as Nintendo and Genesis. Such games would have the advantages of teaching much needed skills while being enjoyable and therefore encouraging learning.

112

KIDVID - Mathematics Games by Kids for Kids--
The Lightspan Partnership, Inc., 2382 Faraday Avenue, Suite 300, Carlsbad, CA 92008; (619) 929-5900
Dr. Inabeth Miller, Principal Investigator

Mr. John Kernan, Business Official
DOE Grant No. DE-FG03-94ER81735
Amount: \$75,000

Nearly 90% of American households with eight-year-old children own video game devices. However, the use of video games as a potential learning opportunity has not been exploited by schools, parents, or the research community. The Phase I project aims to develop three video game prototypes with progressive levels of challenges to help children explore rational number concepts and apply them to the real world. The prototypes will be based upon game ideas generated by children and their teachers. The effort is intended to discover (1) whether the utilization of children to develop educational games results in games that children find appealing; (2) whether video games can be an effective means of increasing children's interest in and understanding of mathematics; and (3) the flexibility and practicality of using a computerized authoring system to prototype and modify products in a fluid design environment. The learning embodied in the video games will be compatible with the curriculum standards set forth by the National Council of Teachers of Mathematics.

Anticipated Results/Potential Commercial Applications as described by the awardee: Children who play with the video game prototypes will have a better understanding of and attitude toward rational number concepts. The commercial outcome of our research will be to create a model for a line of curriculum based educational video games. The products will be marketed to schools as well as homes.

GREEN CAR: SCIENTIFIC APPROACHES TO AUTOMOTIVE INNOVATIONS

113

A Low Emission Alkali Metal Thermal to Electric Converter Automotive Power System--
Advanced Modular Power Systems, Inc., 4667 Freedom Drive, Ann Arbor, MI 48108; (313) 677-4260
Dr. Thomas K. Hunt, Principal Investigator

Dr. Thomas K. Hunt, Business Official
DOE Grant No. DE-FG02-94ER81696
Amount: \$74,558

The Alkali Metal Thermal to Electric Converter (AMTEC) is a static energy conversion device that operates at thermal to electric conversion efficiencies that are independent of size, have reached 19% and

are expected to reach 25% to 30% in early 1995. These systems operate silently, with no moving parts and can utilize any source capable of delivering heat at 700°C to 900°C. Because they are as efficient as small internal combustion engines over a wide range of output (within 5% of peak efficiency from 15% to 85% of full power), but use external combustion, they are expected to have the lowest emissions possible for a given electrical output. Their output is DC, and, with appropriate series connection of modules, AMTEC can deliver voltages to match those provided by the battery systems of electric vehicles either for charging or for direct operation of electric motor drives. While AMTEC systems have been under development for years, recent developments made in programs directed toward spacecraft power systems have led to much simpler cell designs, far higher reliability, greatly improved modeling methods, and a clear path to modules appropriate for the assembly of multi-kilowatt systems. This project will demonstrate the feasibility of this approach through design, analysis, and the fabrication and testing of subscale modules. In Phase I a system design will be developed and used to guide a series of experiments whose results will allow a clear test of the feasibility of the AMTEC approach. Phases II and III will demonstrate full scale module performance and show that they can be assembled into units appropriate for use in a hybrid-electric vehicle. The experimental work in Phase I will develop the first multi-tube vapor-vapor AMTEC module and use its performance to refine the state-of-the-art analytical models for AMTEC. The models will then be used to determine the feasibility of a full scale system and direct the statement of work for Phase II. The Phase II program will have input from the automotive industry.

Anticipated Results/Potential Commercial Applications as described by the awardee: In Phase III, auxiliary power units for hybrid-electric vehicles will be assembled and tested in vehicles. They will be able to improve vehicle range and reduce emissions to well below expected standards. As stand-alone modules, the same AMTEC devices that can be assembled into large systems for vehicles can be utilized as residential generators in continuous gas furnaces, for remote power in recreational vehicles, for rural power generation from biomass fuels, and for cathodic protection of pipelines.

Advanced Catalysts for Ultra-Low Emission Control in Natural Gas Fueled Vehicles--

Goremotive Industries, Inc., 20944 Sherman Way, Suite 206, Canoga Park, CA 91303; (818) 884-0015
Mr. Y. E. Chang, Principal Investigator
Mr. Arthur D. Sweet, Business Official
DOE Grant No. DE-FG03-94ER81772
Amount: \$75,000

Two catalyst formulations are planned which should significantly advance performance and durability of emission control converters for use in light duty vehicles converted for use with compressed natural gas (CNG) or dual (gasoline and CNG) fuels. Research in Phase I will formulate and experimentally examine key performance parameters for (1) catalysts designed to resist sintering and maintain nitrogen oxide reduction activity and three-way catalytic activity at elevated temperatures, and (2) catalysts designed to convert carbon monoxide, non-methane organic compounds, and methane at low temperatures. The feasibility of new flexible configurations of emission control converters capable of three way catalyst (TWC) coupling and specifically designed to exceed Ultra Low Emission Vehicle standards with CNG fuel will be examined. Research tasks will include:

- Development of a sintering-resistant NO_x reduction catalyst designed to operate in (hotter) locations closer to the exhaust manifold than current under-floor converters.
- Evaluation of coatings designed to inhibit oxidation of new commercial ferritic steels used in electrically heated converters (EHC).
- Development of TWC catalyst with high oxygen storage capability and high activity for CO and hydrocarbon oxidation at low temperature.

Anticipated Results/Potential Commercial Applications as described by the awardee: The advanced catalytic system would allow conversion of gasoline vehicles to CNG to produce several significant economic benefits previously not clearly attributable to CNG vehicles. Because the catalyst designs are expected to result in ultra-low emissions for NO_x and non-methane organic compounds, a departure for the traditional reductions solely in CO and particulates, these vehicles could become a potential source of cost-effective emissions reductions aimed at attaining both NO_x and ozone air quality

standards. CNG conversion is effectively a vehicle recycling program; therefore 1) it is cost-effective to reduce emissions from vehicles whose market value exceeds the price offered by scrapping programs; 2) consumers need not purchase a new car to achieve the reductions (as is the case with most alternative vehicle programs; and 3) the emissions reductions are relatively permanent for the life of the vehicle and exceed those reductions achieved by simple replacement with new gasoline engines.

115

A Clean and Efficient Thermophotovoltaic Generator for Electric Vehicles--JX Crystals, Inc., 1105 12th Avenue, Northwest, Suite A, Issaquah, WA 98027; (206) 392-5237

Dr. Lewis M. Fraas, Principal Investigator
Mrs. Jany Xiang Fraas, Business Official
DOE Grant No. DE-FG03-94ER81795
Amount: \$74,932

A quiet, lightweight, clean electric power source will be built, in which natural gas burns continuously in a ceramic tube, the tube glows red hot, and photovoltaic cells receive the infrared radiation from this emitter and convert it to electric power. In effect, "solar" cells are used with a manmade "sun" created by burning natural gas. Because the natural gas is burned at a continuous high temperature in the photovoltaic unit, it is expected to burn more completely and cleanly than it does in the periodically exploding internal combustion engine. Initial benchtop experiments have already shown that this generator is fifty times cleaner with respect to hydrocarbon and carbon monoxide emissions. Such a generator has only recently become feasible as a result of newly fabricated gallium antimonide cells. These new cells are much more sensitive in the infrared spectrum than traditional solar cells. In Phase I, a small benchtop thermophotovoltaic generator will be built, and sufficient data collected to demonstrate that such a generator can operate cleanly and efficiently at economical power densities. The long term goal of this project is to build a generator with sufficient power to charge onboard vehicle batteries, resulting in an electric vehicle without the present constraint of limited driving range. Further, the design of this generator will emphasize cost-effectiveness in volume production, so that this project could lead to commercially viable

products in all present and future markets for electric generators.

Anticipated Results/Potential Commercial Applications as described by the awardée: Thermophotovoltaics generation has the potential to replace all existing small electric generator applications and create several major new markets. As cogenerators of electricity and heat, thermophotovoltaic generators are capable of entering the remote residential market in the next three years. Larger markets include electric vehicles, and electric utility- distributed generation via customer cogeneration in residential and commercial buildings and industrial facilities. Lower cost electricity generation is the benefit driving the creation of these markets, but other important benefits include increased fuel efficiency, lower emissions, and reduced foreign oil dependence.

116

Molecular Composite Plastics for Lightweight Green Cars--Maxdem, Inc., 140 East Arrow Highway, San Dimas, CA 91773; (909) 394-0644

Dr. Mark Trimmer, Principal Investigator
Dr. Matthew Marrocco, Business Official
DOE Grant No. DE-FG03-94ER81806
Amount: \$74,749

It is planned to replace both metals and glass fiber composites in automotive construction. Potential savings in weight of 25% to 40% over current materials and the ability to recycle these new thermoplastics offer major steps toward a fuel efficient Green Car. For example, the Lightweight Materials Program Plan projects that if current vehicles were lightened by only 25% the total U.S. gasoline consumption would drop 13%. The planned new materials are based on new rigid-rod resins. These plastics are stiffer and stronger than any isotropic thermoplastic, with up to four times the stiffness and two times the strength of high performance thermoplastics like polyimides and polyetherketones. In Phase I, the planned new blends are targeted to replace sheet molding compounds (SMC). While no method of recycle exists for currently used SMC body panels, the new blends would contain no fibers and are potentially recyclable. Ultimate properties would allow

displacement of metals, including primary structural applications.

Anticipated Results/Potential Commercial Applications as described by the awardee: The first commercial application for the new materials is expected to be molecular composite sheet for automobile body panels. A weight savings of about 40% would result in addition to full recyclability, and improved surface finish because of the elimination of glass fibers. Ultimately these molecular composites are expected to displace metals in primary structural applications.

117

A Membrane Reactor for the Production of Hydrogen Fuel from Hydrocarbon Liquids-- Membrane Technology and Research, Inc., 1360 Willow Road, Suite 103, Menlo Park, CA 94025; (415) 328-2228

Dr. Ingo Pinnau, Principal Investigator
Ms. E. G. Weiss, Business Official
DOE Grant No. DE-FG03-94ER81808
Amount: \$75,000

Research and development efforts are under way to produce the "green car"—an energy-efficient, pollution-free, economical vehicle that is also appealing to consumers. A good approach to meeting the goals of the "green car" is to use a fuel that is energy-efficient, pollution-free, economical, and safe. This project will investigate an innovative membrane-based process that would make hydrogen feasible as an automobile fuel. Ultrathin metal composite membranes will be used in an on-board membrane reactor to produce extremely pure hydrogen fuel by dehydrogenation of hydrocarbon liquid. The spent liquid is stored in the automobile and recycled at the filling station, enabling the "green car" to use the existing fuel supply network. The use of a hydrocarbon liquid as the hydrogen source eliminates the problem of fuel safety. In Phase I, catalytically active metal membranes on high-temperature polymer supports will be prepared and characterized. The membranes will be installed in a membrane reactor to determine the hydrogen conversion efficiency and production rate. The size, cost, and weight of a membrane reactor to power a 2,000-lb automobile will be estimated. In Phase II, the membranes will be scaled up for a pilot-scale

membrane reactor to demonstrate the continuous production of hydrogen as an automotive fuel.

Anticipated Results/Potential Commercial Applications as described by the awardee: If successfully developed, the resulting lightweight, efficient membrane reactor could be used to generate hydrogen fuel from hydrocarbon liquids in the "green car" of the future.

118

Surface Hardening of Polymeric Composites by High Energy Ion Irradiation--UES, Inc., 4401 Dayton-Xenia Road, Dayton, OH 45432-1894; (513) 426-6900

Dr. Rabi S. Bhattacharya, Principal Investigator
Mr. Robert W. Vukusich, Business Official
DOE Grant No. DE-FG02-94ER81894
Amount: \$74,769

The recent major advances in surface hardening of polymers by ion irradiation opened up the opportunity for replacing many current parts in the automotive industry. There are many gear applications where the use of polymers is desirable from the standpoint of noise, cost, and/or weight reduction. However, polymers tend not to do well in wear and friction applications because of their low hardness compared to steels or other metals suitable for gear applications. High energy (MeV) ion implantation has been shown to improve the hardness of many polymers quite significantly. Surfaces of some polymers became harder than that of steel after ion irradiation. In Phase I, ions at energies in the range 2-6 MeV will be implanted into six different glass reinforced polymers considered for small gear applications in automotive industry. The implanted materials will be characterized for surface hardness, static and dynamic friction coefficients, and wear coefficients. The results will be analyzed with respect to the needs for automotive gear applications.

Anticipated Results/Potential Commercial Applications as described by the awardee: A new method based on high energy (MeV) ion irradiation will be developed for the improvement of surface hardness, friction, and wear properties of glass reinforced polymeric composites. The potential

applications are in the automotive, aerospace, and chemical industries.

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An Energy Efficient Electric Vehicle--Visual Computing Systems Corporation, 9540 Highway 150, Box 250, Greenville, IN 47124; (812) 923-7474
Mr. Roy Kessinger, Jr., Principal Investigator
Mr. Robert J. Westerkamp, Business Official
DOE Grant No. DE-FG02-94ER81898
Amount: \$74,817

This project is pursuing the design and production of a line of integrated mechanical, electronic, and software modules to provide a logical framework within which motion control systems of great efficiency and versatility may be designed and constructed. These products are called general-purpose motion modules (GPMs). GPMs are, in effect, mechatronic electric motor systems, integrating the motor, transmission, sensing, and control functions for a single axis of motion into a lightweight modular package. This functional integration will achieve significant reductions in size and weight, while increasing output torque and

electromechanical conversion efficiency. Due to the high power-to-weight ratio of these devices, as well as their high operating efficiency, automotive applications are particularly appropriate for GPM technology. Phase I will expand the current GPM baseline designs to allow their use in numerous automotive systems. A high-level design will be produced, at the mechanical, electrical, and control levels, of a vehicle employing a regenerative powertrain based on general-purpose motion modules (GPMs). Current GPM designs will be modified to provide the high torque and high efficiency required by practical electric vehicles. Predictions of overall vehicle efficiency will be produced. Throughout the project, computer-based simulation will be employed to facilitate design and to allow system performance to be predicted.

Anticipated Results/Potential Commercial Applications as described by the awardee: The proposed effort will produce motor and controller concepts for high-efficiency passenger cars, commercial trucks, and military vehicles. The concepts for efficient high-torque rotary actuators will be valuable in numerous electric drive applications, including industrial motors, material handling, and robotics.

DESIGN AND APPLICATIONS OF NOVEL MATERIALS

120

Economical Photochromic Films for Solar Thermal Control--EIC Laboratories, Inc., 111 Downey Street, Norwood, MA 02062; (617) 769-9450
Dr. R. David Rauh, Principal Investigator
Dr. A. C. Makrides, Business Official
DOE Grant No. DE-FG02-94ER81743
Amount: \$75,000

The goal of this work is to develop a robust thin film coating, less than 1 μm thick, that can be applied to surfaces, rendering them photochromic in sunlight with respect to both the visible and near infrared components of the solar spectrum. Applied to windows these single layer "chromogenic" coatings are projected by modelling studies to result in large energy savings by solar management, particularly in

buildings dominated by their cooling load. The planned thin film approach would differ from current photochromic technologies which are generally silver-based. Current technologies are not easily adapted to architectural glass and require bulk glass or environmentally sensitive polymer host materials. The coatings will be derived from inorganic transition metal oxides, and are thus expected to be economical in materials and preparation, robust, and not subject to environmental degradation. The objective of Phase I is to demonstrate a new highly active photochromic thin film employing a novel means of sensitization of the metal oxide photocoloration process. The thin films may be prepared by vapor deposition (to be investigated in Phase I) or by thermal decomposition of appropriate precursors, compatible with float glass plant operations. Successful completion of the project will

yield a 6 in. square sample of the new material and preliminary performance and life testing results. This will form a basis of a more extensive Phase II project in which the composition and processing are optimized, and in which the long term environmental stability of the materials is characterized and improved.

Anticipated Results/Potential Commercial Applications as described by the awardee: In the commercial sector, a truly economical photochromic coating would be useful in building windows, automotive windows, sunroofs for thermal and glare control, and for eyewear. Aircraft cockpits would also benefit from photochromic materials both in thermal control and in enhanced visibility of displays in bright sunlight.

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A Novel Method for Manufacture of High Temperature Superconducting Coils for High Temperature Operation--IGC Advanced Superconductors, 1875 Thomaston Avenue, Waterbury, CT 06704; (203) 753-5215

Dr. Leszek R. Motowidlo, Principal Investigator
Mr. B. A. Zeitlin, Business Official
DOE Grant No. DE-FG02-94ER81780
Amount: \$75,000

The primary objective of this project is the development of high temperature superconducting (HTS) coil technology suitable to produce at least one Tesla (T) at pumped liquid nitrogen temperatures. The Phase I project will continue to develop a new approach for increasing the performance of HTS coils for high temperature operation. The technical approach being followed in this work will allow achievement of critical current densities (J_c) equivalent to the best results obtainable by short sample pressing. The achievement of J_c values on the order of 30,000 to 60,000 A/cm² in the final coil configuration would then allow, for the first time, serious consideration of devices to be operated at cryogenic temperatures such as pumped liquid nitrogen (64 K) with magnetic field generation of at least one Tesla.

Anticipated Results/Potential Commercial Applications as described by the awardee: Significant commercial market opportunities for

superconductivity in the near future (10 to 20 years) will be realized in two basic fields. The first is medical (less than 2.5 T) and non-medical (2.5 T to 12 T) applications of nuclear magnetic resonance (NMR) techniques, and the second will be energy technology, including the eventual commercial growth of superconducting magnetic energy storage on both a large (> 10 MJ) and small (1 to 10 MJ) scale. For example, low cost NMR or magnetic resonance imaging magnets requiring only low fields (0.8 to 1 T) and cooled by cryogenic gases to 60 K could be made available.

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Thermophotovoltaic Generator Efficiency Improvement--Quantum Group, Inc., 11211 Sorrento Valley Road, San Diego, CA 92121; (619) 457-3048

Dr. Glen A. Holmquist, Principal Investigator
Dr. Mark Goldstein, Business Official
DOE Grant No. DE-FG03-94ER81838
Amount: \$74,500

The objective of the Phase I effort is to perform a feasibility/modeling study for a high temperature (1700 to 2200°C), combustion powered, high efficiency thermophotovoltaic electrical generator. The combination of existing materials and technologies will be tested and brought together to achieve the high efficiency goal. Superemitters that concentrate radiant flux in quantum transitions emission peaks are available for study and measurement. New photovoltaics that match the superemitter peaks with efficient photon conversion are becoming economically feasible.

Anticipated Results/Potential Commercial Applications as described by the awardee: The result of this effort will be the ability to produce new higher efficiency and environmentally friendly electrical power generators to replace existing systems, in areas such as residential electrical peak load leveling, quiet generator systems, and low nitrogen oxides burners and generators.

A Novel High Strength Ceria-Zirconia Toughened Alumina Ceramic with Superior High Temperature Corrosion and Erosion Resistance--Selee Corporation, 700 Shepherd Street, Hendersonville, NC 28792; (704) 697-2411
 Dr. Giulio A. Rossi, Principal Investigator
 Mr. Kenneth R. Butcher, Business Official
 DOE Grant No. DE-FG05-94ER81859
 Amount: \$75,000

This project will develop a novel ceramic material, made of a ceria-zirconia ($\text{CeO}_2\text{-ZrO}_2$) toughened alumina (Al_2O_3), which is expected to exhibit superior strength and corrosion (alkali, sulphate) and erosion resistance in high temperature environments, such as coal-derived hot gases. This material will be fabricated for convenience in the shape of a reticulated foam in order to provide enough surface area to alkali and sulphate exposure and to compare its performance with other foams with different compositions. The open cell structure will be made by impregnating a polyurethane foam with an aqueous ceramic slurry, followed by drying and firing to burn the organic material and densify the foam struts at high temperatures. Samples of the material will be exposed to alkali- and sulphur-containing species at high temperatures, and the change in physical, chemical, and mechanical properties will be measured, vis-à-vis selected reference materials.

Anticipated Results/Potential Commercial Applications as described by the awardee: A strong, corrosion and erosion resistant $\text{CeO}_2\text{-ZrO}_2$ toughened Al_2O_3 material will be developed. Its primary commercial application is in ceramic particulate filters for coal-derived hot gases, where it could replace inadequate existing materials such as aluminosilicates and non-oxide ceramics.

Design and Applications of Close-Spaced Thermionic Converters with Novel Isothermal Electrodes--Space Power, Inc., 621 River Oaks Parkway, San Jose, CA 95134; (408) 434-9500
 Mr. Gary O. Fitzpatrick, Principal Investigator
 Mr. Joseph A. Dodson, Business Official
 DOE Grant No. DE-FG03-94ER81864
 Amount: \$74,342

It will be demonstrated in Phase I by analysis and experiment that electrodes for thermionic converters having heat pipes incorporated in the electrode structure accommodate high interelectrode heat flux without distortion. These results will enable close-spaced converters with electrode gaps of 5 μm or smaller. Such a converter can be 13% efficient with an emitter temperature of only 1300 K. This is a new approach to enhanced energy conversion efficiency which can significantly increase overall efficiency of power generation at competitive cost. The analysis of the electrodes will consider heat transfer, mechanical deformation, and thermionic performance. Trade-off of heat flux and physical dimensions will lead to an optimum design. Experiments will use laser interferometry to characterize and confirm the capabilities of the isothermal electrode. An application study will quantify the commercial benefits that can reasonably be expected from this improved performance, which can be commercialized in this decade. Follow-on work would include fabrication of an operating module of close-spaced thermionic converters with the isothermal electrodes.

Anticipated Results/Potential Commercial Applications as described by the awardee: Thermionic conversion at high efficiency and relatively low temperatures can be incorporated as topping cycles to steam and/or gas turbine electric generation, as solar thermal generators, and for cogeneration. Significantly enhanced overall efficiencies mean benefits economically and in resource utilization.

Rare Earth Endohedral Fullerenes as New Nonlinear Optical Materials--TDA Research, Inc., 12345 West 52nd Avenue, Wheat Ridge, CO 80033; (303) 940-2301
 Mr. John Michael Alford, Principal Investigator
 Mr. Michael E. Karpuk, Business Official
 DOE Grant No. DE-FG03-94ER81880
 Amount: \$75,000

Computers using light beams instead of wires are the fastest known type of computer. Many of the main components of optical computers such as the optical switches that are its fundamental building blocks are

fabricated from third order nonlinear optical (NLO) materials. Unfortunately, the best currently available third order materials have NLO effects that are two to four orders of magnitude smaller than are needed for commercial devices driven by moderate power diode lasers. Endohedral fullerenes (closed cage carbon molecules with a rare earth atom or atoms trapped inside) are believed to possess large optical nonlinearities. Significantly, these predicted nonlinear effects are optimally located for use with infrared (IR) laser diodes. Additionally, electronic interactions between the fullerene and metal atom may provide a natural way to obtain optical control of the materials properties and allow for optical switching of the nonlinearity. In spite of the fact that endohedral fullerenes were first produced almost three years ago, insufficient material exists to determine if they actually have the NLO properties predicted by the theorists. This is primarily a result of the difficulty in purifying the materials. Therefore, in Phase I a new type of large scale preconcentration step will be used along with high performance liquid chromatography to purify sufficient quantities of endohedral fullerenes for NLO characterization. The optical properties of the materials will be measured using four wave mixing spectroscopy and other types of nonlinear spectroscopy.

Anticipated Results/Potential Commercial Applications as described by the awardee: Endohedral fullerenes are predicted to have large NLO properties that would make them ideal materials for use in devices such as optical computers. Additionally, the development of a practical method for producing endohedral fullerenes will allow sales of these materials to researchers and, ultimately, to commercial users.

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Development of Metal Hydride Materials for High Coefficient of Performance Heat Pumps--
Thermal Electric Devices, Inc., 1009 Bradbury Drive,
Southeast, Albuquerque, NM 87106; (505) 272-7505
Dr. K. Thomas Feldman, Jr., Principal Investigator
Dr. Charles Stein, Business Official
DOE Grant No. DE-FG05-94ER81890
Amount: \$74,999

This project will develop improved metal hydride materials for a new hydride heat pump that is environmentally clean and potentially twice as efficient as the best current systems. New thermodynamic processes have been developed for hydride heat pumps that are significantly more efficient and utilize no chlorofluorocarbons (CFCs), which must be phased out of use by 1995. The best current refrigerators operating with less damaging hydrochlorofluorocarbon (HCFC) refrigerants have a coefficient of performance or COP = 1.5, while the proposed new hydride heat pump has a theoretical COP = 3.3. Current research has demonstrated that hydride heat pumps are feasible and very promising, but improved hydride materials are needed to achieve their full potential. Improved hydride heat exchangers are needed that have more rapid heat transfer and hydrogen flow. Hydrides have low thermal conductivity so that rapid heat transfer into and out of the hydride bed is difficult. Also, hydride particles tend to become smaller and compacted during use and this blocks the free flow of hydrogen into and out of the hydride bed. In Phase I the approach to the improved hydride materials involves coating the metal hydride particles with a thin layer of copper and then compressing the coated particles into porous heat exchangers which can provide more rapid and effective heat transfer and hydrogen flow. When developed, this technology will allow nearly a 50% reduction in the electric power required by refrigerators/freezers, air conditioners, and heat pumps used in both domestic and commercial applications including vehicles. The new system will be smaller, weigh less, and cost about the same as conventional refrigeration equipment. The system does not require CFCs or HCFCs, so it is inherently clean and has no adverse environmental impact.

Anticipated Results/Potential Commercial Applications as described by the awardee: Phase I will develop, build, and test improved hydride materials and heat exchangers optimized for a new high performance hydride heat pump. Based on the positive results of preliminary research, it is anticipated that the research will develop improved hydride materials and highly effective hydride heat exchangers that will allow nearly the full potential of the more efficient hydride heat pump to be realized.

MATERIALS SCIENCES INSTRUMENTATION

127

X-Ray Absorption Spectroscopy for Trace Analysis of Chemical Phase and Composition--
Advanced Fuel Research, Inc., 87 Church Street, P.O.
Box 380379, East Hartford, CT 06138-0379; (203)
528-9806

Dr. David B. Fenner, Principal Investigator
Dr. David G. Hamblen, Business Official
DOE Grant No. DE-FG05-94ER81861
Amount: \$74,674

X-ray absorption spectroscopy (XAS) based at synchrotron facilities is an established research tool in a variety of fields including biochemistry, catalysis, and materials science. For trace analysis, XAS offers important phase information as well as elemental composition. Commercialization will depend on increased performance of the x-ray detection system. This Phase I project will leverage university expertise and DOE laboratory facilities by transferring improved techniques to the private sector small business. An improved detector system is planned, based on an array of silicon avalanche photodiodes having the following advantages: (1) operation at or near room temperature, (2) internal signal gain and lower noise, (3) good efficiency up to ~15 keV, and (4) good energy discrimination. This detector will improve on conventional germanium (Ge) and silicon (lithium) Si(Li) detectors primarily by elimination of the bulky cooling apparatus, thereby reducing the cost and increasing the overall flexibility. Application to analysis of the chemical phase of trace metal compounds in soils will form an early demonstration of the power of this technique. The information gained from this project will also contribute to evaluation of the potential for application of the technology to related areas of x-ray research.

Anticipated Results/Potential Commercial Applications as described by the awardee: Benefits include an increase in the cost effectiveness of the XAS technique, thereby enhancing the commercial potential for analytical services based on this technique for use in the growing fields of biochemistry, environmental control and remediation,

and others. There is also a considerable market for an inexpensive, high-performance x-ray detector in the many government, academic, and industrial research institutions which already utilize XAS in their research activities.

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An Apparatus for Structural Analysis of High Temperature Materials Using Synchrotron Radiation--Containerless Research, Inc., 910
University Place, Evanston, IL 60201-3149; (708)
467-2678

Dr. Shankar Krishnan, Principal Investigator
Dr. Paul C. Nordine, Business Official
DOE Grant No. DE-FG02-94ER81732
Amount: \$74,978

X-ray and neutron scattering are powerful techniques for structural measurements on solids and liquids. Although structural analyses of high temperature materials are important, they have been limited by two sources of error. First, the materials of interest become contaminated by reaction with their containers. Second, the containers produce unwanted scattering and absorption of the probe beams. These errors combine to produce intractable problems in the analysis of data. These problems will be eliminated in this project by applying containerless techniques for x-ray and neutron scattering measurements on high temperature liquids and solids, both metals and ceramics. The methods for achieving containerless conditions will be electromagnetic levitation for metallic materials and conical nozzle levitation for both metals and ceramics. The electromagnetic levitation approach was demonstrated in preliminary neutron scattering experiments. The conical nozzle method was demonstrated in the laboratory on molten aluminum oxide and other ceramics. The main goal of the project is to develop the x-ray analysis of high temperature materials using the conical nozzle technique with synchrotron radiation. The conical nozzle levitation method will be investigated for metallic and ceramic liquids of interest during Phase I. The research will include synchrotron scattering experiments on levitated materials of known

structure, using the National Synchrotron Light Source. Phase II would provide a portable apparatus for application at synchrotron radiation and neutron beam facilities for structural analyses of high temperature materials.

Anticipated Results/Potential Commercial Applications as described by the awardee: Successful completion of Phases I and II will provide a breakthrough in making accurate structural measurements of high-temperature materials routinely feasible. It will eliminate the extreme difficulty of container interactions at high temperatures. It will enable structural studies on highly corrosive materials of industrial importance such as battery and plating materials, slags, and semiconductors. The planned work will provide a new analytical tool to apply synchrotron radiation in measurements of scientific and industrial interest.

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A Novel Detector for Neutron Diffraction Studies--Radiation Monitoring Devices, Inc., 44 Hunt Street, Watertown, MA 02172; (617) 926-1167
Dr. Gerald Entine, Principal Investigator
Dr. Gerald Entine, Business Official
DOE Grant No. DE-FG02-94ER81841
Amount: \$75,000

The objective of this project is to develop a new type of large area position sensitive neutron detector for use in diffraction studies. The detector would use a liquid crystal sensing mechanism to provide a large area high resolution (comparable to photographic methods) detector which would be inexpensive to produce. To demonstrate the feasibility of this concept in Phase I, several technical areas need to be examined. First, research will be carried out on modifying the solution chemistry of the liquid crystal systems to determine if neutron sensitive boron compounds can be incorporated. Second, the electro-optic characteristics of candidate liquid crystal systems will be examined, and finally, the modified liquid crystal systems will be tested for neutron sensitivity. Phase II of this effort will continue the research and examine the fabrication of prototype position sensitive arrays. The detector would provide substantially increased performance at lower cost than existing detectors used in neutron diffraction studies

Anticipated Results/Potential Commercial Applications as described by the awardee: The planned detector would offer performance advantages over existing instruments and would be inexpensive to manufacture. The resulting detectors would find widespread use in material science research and may also be useful in industrial neutron tomography applications.

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An Analytical Research Materials Characterization Facility Based on Synchrotron Radiation--X-Ray Analytics, Ltd., Box 678, Upton, NY 11973; (708) 887-9941
Dr. Kevin L. D'Amico, Principal Investigator
Dr. Kevin L. D'Amico, Business Official
DOE Grant No. DE-FG02-94ER81901
Amount: \$74,710

This work represents an effort to establish a materials characterization facility at a synchrotron radiation source which can be utilized on a fee-for-service, pay-as-you go basis by industrial research, development, and production organizations. The ultimate outcome of the program is the existence of a beamline facility dedicated to both analytical service and contract research. The Phase I effort will be to identify the materials and the analytical problem that can be addressed with a synchrotron radiation technique. This technique will be the basis for the beamline capabilities. Experiments will be performed on the materials to demonstrate that routine results can be obtained. The potential for scale-up will be addressed, with the goal of showing that the measurements can be done routinely at an existing synchrotron radiation source. A conceptual design for a prototype beamline which is optimized for routine analytical measurements will be developed.

Anticipated Results/Potential Commercial Applications as described by the awardee: This effort will result in the growth of the market for the synchrotron radiation-based characterization of materials by industrial research organizations nationwide and in the further use of these techniques by industrial laboratories not currently utilizing them. This will provide for the more effective transfer of technology from the federally-funded laboratories, where the synchrotron radiation

facilities exist, to the private research laboratories not currently using them.

IMPROVED ONSTREAM METHODS OF NONDESTRUCTIVE EVALUATION

131

Application of the Meandering Winding Magnetometer to an In-Situ Determination of Age Related Degradation--Jentek Sensors, Inc., 1616 Soldiers Field Road, Boston, MA 02135; (617) 254-5552

Dr. Neil J. Goldfine, Principal Investigator
Dr. Neil J. Goldfine, Business Official
DOE Grant No. DE-FG02-94ER81792
Amount: \$75,000

Many of the structures and components important to safe operation of power plants are susceptible to age related degradation. Steam lines suffer creep damage, Inconel steam generator tubes suffer stress corrosion cracking, reactor vessels become embrittled, and cyclically loaded components may experience fatigue damage. Nondestructive characterization of these age related degradation mechanisms would provide the information required for informed decisions regarding plant maintenance and life extension. No techniques exist that provide adequate information. A novel sensor, the Meandering Winding Magnetometer (MWM), offers considerable promise as a new means of nondestructive, on-line, in situ material characterization. It has already been shown to be capable of precise measurements of conductivity in nonferromagnetic materials. Conduc-

tivity is known to be sensitive to age related degradation, and permeability may be as well. The MWM also offers the possibility of measuring depth related variations in electromagnetic properties. This feature may be especially useful as several forms of age related degradation are known to vary with depth. Phase I will investigate extending the capability of the MWM to provide conductivity and permeability data for ferromagnetic materials. It will also investigate the relationship of material properties and sensor response to fatigue damage, one form of age related degradation. Phase II will extend MWM inspection capabilities to address creep damage. It will also include integrating the MWM sensor into a field portable prototype instrument.

Anticipated Results/Potential Commercial Applications as described by the awardee: Phases II and III should produce a complete, field portable inspection system capable of nondestructively characterizing several age related damage mechanisms in a variety of materials. For power plant operators, this could be a powerful tool for managing age related degradation and making critical decisions related to plant life extension. The concept has great commercial potential, since it could save millions of dollars in reduced downtime caused by catastrophic failures.

ADVANCED GEOPHYSICAL IMAGING IN GEOSCIENCES RESEARCH

132

A Superconducting Magnetometer/Gradiometer for Advanced Geophysical Imaging--Conductus, Inc., 10623 Roselle Street, San Diego, CA 92121; (619) 550-2700

Dr. Douglas N. Paulson, Principal Investigator
Dr. Duane B. Crum, Business Official
DOE Grant No. DE-FG03-94ER81730
Amount: \$75,000

There has recently been increased interest in the use of active electromagnetic measurements to provide improved imaging of subsurface structures, particularly for enhanced oil recovery and environmental issues such as ground water contamination, underground petroleum leaks, and remediation of hazardous waste sites. Borehole-to-borehole and surface-to-borehole measurements are of particular interest since they provide better information about the subsurface structure than a

surface-to-surface measurement. Although induction coils are available for use in boreholes, it is difficult to get good sensitivity to horizontal fields. These coils are expensive and/or physically large which tends to limit their widespread use. Recent advances in the performance of superconducting quantum interference device (SQUID) sensors made from the new high-temperature superconductors have been significant. It is now possible to use these sensors to build compact, low-noise, multi-element magnetometer arrays. Phase I will develop a simple prototype magnetometer system incorporating one or more high-temperature SQUID sensors. This magnetometer will be interfaced to a ruggedized data acquisition system and its performance and noise level measured in a variety of operating conditions.

Anticipated Results/Potential Commercial Applications as described by the awardee: This new sensor, along with its associated analysis tools, should provide significant benefits in a number of surface and borehole applications including environmental remediation, enhanced oil recovery, unexploded ordnance detection, ground water contamination, and petroleum leakage.

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High Resolution Mapping of Mechanical and Flow Properties of Subsurface Structure from New Methods for Acoustic Logging Data Processing--New England Research, Inc., 76 Olcott Drive, White River Junction, VT 05001; (802) 296-2401

Mr. Xiaoming Tang, Principal Investigator
Mrs. Beth K. Potter, Business Official
DOE Grant No. DE-FG02-94ER81818
Amount: \$74,962

In the exploration and production of oil and gas reservoirs and in groundwater studies, there is a need for high resolution mapping of fluid flow channels in the subsurface formation. The increased resolution provides accurate locations of the flow channels and helps enhance the recovery of hydrocarbon resources. For environmental applications, the accurate mapping of the flow channels will help track contaminants and pollutants associated with groundwater flow. To achieve this goal, effective sensing technologies and high resolution processing techniques need to be developed. The

objective of this project is to develop high resolution techniques for single well acoustic logging data processing to obtain in-situ estimates of permeability and mechanical properties of subsurface formation and to locate and characterize bedrock fractures. As a result, subsurface flow systems and their transmissivity (or permeability) will be accurately mapped to provide useful information for enhanced oil and gas recovery and for the characterization and remediation of soil and groundwater contamination problems. Phase I will address two major tasks. The first is to develop the high resolution processing technique to include the conventional full waveform acoustic logs. The second is to develop analysis methods for high resolution permeability estimation from tube waves and test the methods using available data. The completion of these tasks will determine the applicability of the proposed techniques for high resolution mapping of subsurface structure.

Anticipated Results/Potential Commercial Applications as described by the awardee: High resolution techniques to resolve subsurface flow units from acoustic logging data processing should result from this project, as well as a high resolution processing software package that will be commercially available to oil and gas, environmental, and hydrological industries.

CHEMICAL SCIENCES RESEARCH

134

An Advanced Electrochemical Sensor for the Simultaneous Analytical Measurement of Three Chemical Species--Andcare, Inc., 2810 Meridian Parkway, Suite 152, Durham, NC 27713; (919) 544-8220

Dr. Marek Wojciechowski, Principal Investigator
Ms. Carolyn J. Henkens, Business Official
DOE Grant No. DE-FG05-94ER81706
Amount: \$75,000

The requirements of complex sample monitoring present a growing need for a new generation of highly specific enzyme electrodes with multi-analyte, multi-signal capability. This project's objective is to establish the feasibility of novel electrochemical sensors based on the combination of immobilized enzymes and colloidal gold technologies. The specific goal to be pursued in Phase I is to demonstrate the feasibility of an in-vitro lipid profile diagnostic device for the simultaneous detection of total cholesterol, high density lipoproteins, and triglycerides using a disposable biosensor. This lipid profile testing is an important part of current recommendations for reducing cardiac risk and for monitoring therapy for millions of individuals with cardiovascular disease. Deposition of colloidal gold with immobilized enzymes onto separate channels of a multi-channel surface to provide spatially resolved, multi-signal enzyme electrodes can ultimately lead to a new generation of multi-analyte sensors.

Anticipated Results/Potential Commercial Applications as described by the awardee: A new marketable micro-scale, multi-analyte sensor based on novel enzyme immobilization methods will result in a device of improved rapid analytical characterization of multi-component systems.

135

High-Performance Membranes for Gas, Vapor, and Liquid Separations--Bend Research, Inc., 64550 Research Road, Bend, OR 97701-8599; (503) 382-4100

Dr. Dwayne T. Friesen, Principal Investigator

Dr. Rod Ray, Business Official
DOE Grant No. DE-FG03-94ER81903
Amount: \$75,000

Separation processes to recover and purify products account for more than 40% of the energy demand in the Chemical Process Industry (CPI), but membrane processes have gained only a small share of this major market. Conventional membranes have had limitations that have precluded their widespread acceptance in the CPI and other industrial settings. Specifically, membranes either could not withstand exposure to harsh solvents and high temperatures involved in industrial separations or lacked the high permeability and high selectivity to be commercially practical. The goal in this project is to develop a new class of polymers that addresses these limitations. The plan is to apply these high-selectivity, high-permeability polymers to unique solvent- and temperature-resistant hollow-fiber supports to form thin-film-composite membranes suitable for use in the CPI. These membranes will be suitable for applications involving the separation of aromatics from aliphatics (e.g., benzene from gasoline) and olefins from paraffins (e.g., propylene from propane). Phase I, should demonstrate the feasibility of using membranes based on this new class of polymers for aromatic/aliphatic and/or olefin/paraffin separations. A series of membranes will be incorporated into small-scale (200-cm²) solvent- and temperature-resistant hollow-fiber modules, and tested extensively. Phase II will optimize the polymers for separation targets, make larger (1m²) modules, and perform pilot-scale tests. The tests will generate the data necessary to set specific technical and marketing targets for commercialization of the technology in Phase III.

Anticipated Results/Potential Commercial Applications as described by the awardee: The polymers to be developed in this project--combined with the solvent- and temperature-resistant hollow-fiber supports developed in previous--work should make possible the use of membrane-based separation systems for a range of applications in CPI. In addition to the separation of aromatics from aliphatics and olefins from paraffins (two of the largest classes of separation in the CPI), other types

of separations may be possible, such as the separations of ethyl benzene from styrene or the separation of butylene isomers.

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Photoaffinity Immobilization of Fusion Proteins on Biosensor Surfaces--BSI Corporation, 9924 West Seventy Fourth Street, Eden Prairie, MN 55344; (612) 829-2715

Dr. Patrick E. Guire, Principal Investigator

Mr. Stephen A. Richards, Business Official

DOE Grant No. DE-FG02-94ER81720

Amount: \$74,280

This project is designed to resolve a critical and enduring obstacle to the development of dependable biosensor systems for the timely detection of toxic and infectious agents. A passivated sensor surface will be developed that will associate uniquely with the specific binding protein in its crude source solution and, upon activation by light, covalently bond this protein functionally oriented in a stabilizing, biomolecule-compatible environment. A trifunctional amino acid will be derivatized on one site with a photoactivatable reagent capable upon illumination of forming covalent bonds with essentially any organic target group (including all proteins) under mild reaction conditions. This reagent will then be thermochemically bonded to a ligand for the specific binding protein and to the sensor surface previously passivated with a photoreactive hydrogel, to provide an essentially aqueous environment containing chosen ligand and photoreactive groups adjacent on the sensor surface. This passivated photoaffinity sensor surface will be exposed to aqueous protein mixtures and tested for its efficiency and specificity in photochemical immobilization of the desired binding protein, as well as the storage and use stability of the immobilized sensor protein. In the Phase I effort, a passivating coating for glass surfaces and a photoreactive trifunctional reagent will be prepared, which will be reacted with the passivated surface and with a ligand to provide a photactivatable affinity surface. This photoaffinity glass is expected to reduce non-specific protein binding by at least 75% and to immobilize the fusion protein with greater than 50% recovery of DNA-binding activity. Phase II will optimize the reagents and coating process for two or more fusion proteins and demonstrate the feasibility

of this chemistry for patterned immobilization on biosensor surfaces.

Anticipated Results/Potential Commercial Applications as described by the awardee: Civilian uses of this biomolecule-compatible photoaffinity sensor surface technology are expected to include the monitoring for hazardous and metabolic (health-relevant) substances in water, air, animal feeds, foods, and physiological fluids. The Department of Defense could use the technology in the development of one or more advanced sensor devices for the timely detection of hazardous chemical and biological agents in water, air, and materials.

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Organic-Inorganic Composite Membranes for Gas Separation and Vapor Permeation--CeraMem Corporation, 12 Clematis Avenue, Waltham, MA 02154; (617) 899-0467

Dr. Richard J. Higgins, Principal Investigator

Dr. Robert L. Goldsmith, Business Official

DOE Grant No. DE-FG02-94ER81723

Amount: \$75,000

The development of specifically engineered polymers and appropriate module designs in the past decade has made possible the commercialization of gas separation membrane technology for several industrial applications. Since currently available membranes and modules are based upon use of organic polymeric materials, they generally are limited to applications involving temperatures of less than about 100°C. However, there are several potential commercial applications for gas separation membrane technology that involve temperatures in the range of about 100°C to 300°C. For these, commercially viable membranes or modules are currently unavailable. In Phase I, cost-effective gas-permeable membrane modules based on low-cost ceramic supports will be developed. Such modules will be designed for use at temperatures in the range of 100° to 300°C. An innovative method will be used to apply thin, defect-free membranes, based on thermally resistant polymers, to the ceramic supports. The resulting membrane modules will subsequently be tested at temperatures ranging from 100°C to 300°C for gas separation and vapor permeation properties using two-component gas mixtures.

Anticipated Results/Potential Commercial Applications as described by the awardee: The gas separation/vapor permeation devices to be developed in this project, if successfully scaled up to production-scale ceramic modules in Phase II, would provide a potentially economic membrane-based alternative to competing technologies for many elevated temperature gas separation processes in industrial chemical manufacturing and the petrochemical and refining industries.

138

Electrode Materials for Rechargeable Lithium Batteries--Materials and Electrochemical Research Corporation, 7960 South Kolb Road, Tucson, AZ 85706; (602) 574-1980

Dr. R. O. Loutfy, Principal Investigator

Dr. J. C. Withers, Business Official

DOE Grant No. DE-FG02-94ER81805

Amount: \$75,000

Fullerenes are a newly discovered form of carbon (graphite and diamond are the other two forms) with distinctive properties and an unusual molecular structure. Preliminary investigations indicated that fullerene electrode materials exhibit unique electrochemical properties. In this Phase I effort, fullerene nanotube structures will be investigated as novel electrode materials for lithium ion storage and supply for rechargeable lithium batteries. Fullerene electrodes will be fabricated by various techniques and fully characterized. The nature of the electrochemical charging and discharging of fullerene nanotubes as a function of operating conditions will be established. The lithium intercalated fullerene nanotubes as a function of operating conditions will be established. The lithium intercalated fullerene (C_nLi_x) electrodes will also be characterized including their capacity, stability, charge and discharge characteristics, and efficiency to establish their viability for a high efficiency secondary battery as a power source for portable electronic equipment.

Anticipated Results/Potential Commercial Applications as described by the awardee: Fullerenes are a newly discovered material with potentially unique properties. Preliminary results indicate that fullerene electrodes could be used to store energy with applications in secondary batteries. The feasibility of this concept could lead to novel

electrochemical systems for energy storage and generation.

139

Highly Selective Membranes for the Separation of Organic Vapors Using Super-Glassy Polymers--Membrane Technology and Research, Inc., 1360 Willow Road, Suite 103, Menlo Park, CA 94025; (415) 328-2228

Dr. Ingo Pinnau, Principal Investigator

Ms. E. G. Weiss, Business Official

DOE Grant No. DE-FG03-94ER81811

Amount: \$75,000

The recovery of organic compounds from air and of higher hydrocarbon vapors from methane are related separations of considerable industrial importance. Membranes able to preferentially permeate the minor organic component are being developed for both of these applications. For an efficient process, a high organic vapor/permanent gas selectivity is required. Conventional glassy polymers, which are selective for the permanent gas over the organic vapor, are suitable for this application. Rubbery polymers, which are organic vapor selective, are in commercial use, but have inadequate selectivity for many applications. Recent work showed that multi-free-volume, super-glassy polymers such as poly(1-trimethylsilyl-1-propyne) [PTMSP] can exhibit a butane/methane selectivity of 30 with the mixed gases. This selectivity is the highest ever observed for this important mixture and is completely unexpected for a glassy polymer. The reason for this extraordinary result is related to the high free volume and the large intermolecular chain spacing of the super-glassy polymer. In this Phase I project, a detailed study will be conducted of the vapor separation properties of PTMSP, related polyacetylenes, and blends thereof with a number of important organic vapor/gas mixtures. In contrast to results of previous studies of high free volume glassy polymers with permanent gases, these polymers are expected to show stable permeation properties in the presence of organic vapors.

Anticipated Results/Potential Commercial Applications as described by the awardee: Membranes made from high-free-volume glassy polymers could have a significant impact on many important industrial vapor separations. Possible

applications include recovery of high hydrocarbons from natural gas, removal of hydrocarbons from hydrogen in the petrochemical industry, and recovery of hydrocarbon vapors from gasoline storage tanks. The superior selectivity and permeability of super-glassy polymers relative to state-of-the-art rubbery membranes will make membrane systems competitive with conventional separation methods such as cryogenic separation in these or other applications.

140

Novel High Performance Glassy Polymer Composite Membranes for Gas Separation--
Membrane Technology and Research, Inc., 1360 Willow Road, Suite 103, Menlo Park, CA 94025; (415) 328-2228

Dr. Richard W. Baker, Principal Investigator
Ms. E. G. Weiss, Business Official
DOE Grant No. DE-FG03-94ER81810
Amount: \$75,000

In the last decade, many high-performance glassy polymers, such as polyimides, that combine high gas permeability and high selectivity for one gas over another have been developed. Although these new membrane materials have vastly better intrinsic gas separation properties than the materials in current use, essentially none has been used in commercial

membranes. The problem is the lack of adequate, reproducible, large-scale membrane fabrication technology that is applicable to these polymers. In this Phase I project, a new method will be developed for preparing high-performance membranes from glassy polymers. Unlike existing commercial membranes made from glassy materials, the membranes will be multilayer composites in which the glassy selective layer is coated onto a high-flux support. The support itself will have two layers, a microporous substrate and a thin, highly permeable sealing layer. General principles will be derived for making optimized multilayer composite membranes with selective layer thicknesses of less than 0.1 μm from any given glassy polymer, and membranes with potential applications for specific gas separation applications will be identified.

Anticipated Results/Potential Commercial Applications as described by the awardee: A general method of producing ultrathin, defect-free composite membranes with highly selective glassy polymers on a commercial scale would have a significant impact on many gas separation applications such as oxygen/nitrogen separation or removal of carbon dioxide or hydrogen sulfide from natural gas. The use of advanced composite membranes would dramatically improve the overall process economics, and make membrane systems competitive with conventional separation methods in these or other applications.

HIGH PERFORMANCE COMPUTING RESEARCH

141

Parallelization of Pseudospectral Algorithms for Electronic Structure Calculations--
Schrödinger, Inc., 80 South Lake Avenue, Suite 735, Pasadena, CA 91101; (818) 568-9392

Dr. Murco N. Ringnald, Principal Investigator
Dr. Murco N. Ringnald, Business Official
DOE Grant No. DE-FG03-94ER81852
Amount: \$74,880

Electronic structure programs are becoming an increasingly powerful tool for solving chemical and biological problems without costly experiments, but

in order to use current and future computer hardware to maximal advantage, they must be parallelized efficiently. The pseudospectral (PS) approach utilized in the previously developed PS-GVB software package is grid-based, permitting a well-balanced distribution of tasks for each region of the grid, which will lead to effective parallelization. The resulting increase in speed will make PS-GVB even more useful for ab initio predictions of electronic structure of large molecules. Phase I will parallelize the most computationally intensive portions of PS-GVB: the assembly of the least-squares operator, the Fock matrix, the GVB Hamiltonians, and the Lanczos-type eigensolver used

for updating the wavefunction during the self-consistent field process. The resulting program modifications will be tested using Parallel Virtual Machine (PVM) software on workstation clusters. The ultimate Phase III goal of the parallelization effort is a multifunctional software package that distributes all tasks effectively when run on a wide variety of massively parallel processors and clusters.

Anticipated Results/Potential Commercial Applications as described by the awardee: The complete, parallelized PS-GVB program should be of use to a large number of researchers in the chemical, biological, and materials sciences in both government and industry. We expect that for many applications, the unique mixture of functionality and efficiency in parallel PS-GVB will make it the only effective solution.

ATMOSPHERIC MEASUREMENT AND SAMPLING TECHNOLOGIES

142

A Tunable Room Temperature Infrared Laser for Measuring Atmospheric Pollutants--Aerodyne Research, Inc., 45 Manning Road, Billerica, MA 01821; (508) 663-9500

Dr. Roger S. Putnam, Principal Investigator

Dr. Charles E. Kolb, Business Official

DOE Grant No. DE-FG02-94ER81698

Amount: \$74,911

Solid state laser sources currently available for measuring greenhouse gases, combustion products, and other species across the 3 to 30 micron region are lead salt diode lasers which operate at liquid nitrogen temperatures. Practical problems include the need for cryogenic cooling, erratic tuning behavior, and limited availability of single mode devices in this region. The opportunity exists to apply inexpensive, room temperature diode lasers which are now readily available with enough power to directly drive a nonlinear difference-frequency infrared generator. The facts that the new diode lasers produce enough power, are available with 10 MHz linewidths without an external cavity, are tunable, and are remarkably efficient make this application an immediate opportunity. The Phase I objectives involve the basic demonstration of generating tunable infrared in the 10 micron region using diode lasers and a gallium selenide crystal with a unique optical design which compensates for beam walk-off and permits the wide tunability of an angle-tuned system with nearly the same conversion efficiency possible in a 90° phase-matched system. The calculated 10 micron power of 0.25 microwatts will result in the desired absorption sensitivity of

$10^{-5}/\text{cm}$ in one second, using a standard 1 mm mercury cadmium telluride detector with a detectivity of 4×10^{10} and a 0.6 meter long multipass cell with a 100 meter path length.

Anticipated Results/Potential Commercial Applications as described by the awardee: An inexpensive tunable source of narrowband infrared permits the construction of air monitoring equipment for a wide variety of pollutants. The market for this instrument already exists in this period of increased environmental concern, attendant legal issues, and new regulations.

143

A Robust Gas Monitor for Remote Environments--DR Technologies, Inc., 12555 High Bluff Drive, Suite 280, San Diego, CA 92130-2056; (619) 794-9607

Dr. Edward A. Johnson, Principal Investigator

Mr. Lyle E. Dunbar, Business Official

DOE Grant No. DE-FG03-94ER81738

Amount: \$74,888

Infrared (IR) absorption spectroscopy is a standard laboratory technique for analyzing gas samples, but good IR absorption instruments are expensive, complicated, and delicate, sharply limiting their usefulness for remote and unattended atmospheric monitoring. This project will develop a rugged, self-calibrating IR absorption sensor that has many of the desired characteristics. With no moving parts, this device can measure concentrations of many gasses by measuring spectra approaching the quality

of laboratory IR absorption instruments, at a cost comparable to simple catalytic sensors. In its ordinary operating mode, this multispectral sensor operates at high pulse rates and provides accurate chemical information on a few millisecond time-scale for immediate use in an active feedback control system. A unique feature of this device is that it is self-referencing; this should provide excellent stability and allow for long counting times with phase-locked detection and a consequent improvement in sensitivity. The Phase I project will evaluate the sensitivity of a multispectral sensor using phase-locked detection and self-referencing for stability. In addition, the Phase I project will explore photoacoustic detection and extended sampling with unclad optical fibers in order to extend the detection limits. These tests will establish the basic design and performance characteristics of a prototype instrument to be built and demonstrated in Phase II.

Anticipated Results/Potential Commercial Applications as described by the awardee: An analytical chemical sensor that is highly sensitive, selective, robust, and of low cost will have wide commercial and government applications for industrial process control and environmental monitoring. This would be an important scientific tool for ecological and atmospheric research.

144

A Subvisible Volcanic Dust Cloud Imager--
Physical Sciences, Inc., 20 New England Business
Center, Andover, MA 01810-1077; (508) 689-0003

BACTERIAL IDENTIFICATION AND SAMPLING

145

Development and Application of Gene Probes to Determine Degradation Potential and to Improve In-Situ Bioremediation Efforts--
Envirogen, Inc., 4100 Quakerbridge Road,
Lawrenceville, NJ 08648; (609) 936-9300
Dr. Robert J. Steffan, Principal Investigator
Mr. William J. Guarini, Business Official

Dr. David M. Sonnenfroh, Principal Investigator
Mr. George E. Caledonia, Business Official
DOE Grant No. DE-FG02-94ER81830
Amount: \$75,000

This project will develop a design for a prototype airborne, remote, subvisible volcanic dust cloud sensor. This innovative, compact instrument is based on a passive, tuneable, infrared, imaging spectroradiometer. The sensor exploits differences in the particle absorption cross sections between silicon dioxide (SiO_2) and water in the 8 to 12 μm region to sensitively detect and discriminate between hazardous dust clouds and nonhazardous natural water clouds by their thermal self-emission. This instrument will have the sensitivity to provide this discrimination at distances of over 15 miles. The Phase I effort includes airborne instrument design and laboratory validation experiments.

Anticipated Results/Potential Commercial Applications as described by the awardee: The project will result in a conceptual design for an airborne imaging spectroradiometer capable of detecting and discriminating between hazardous and nonhazardous subvisible aerosol clouds. Demonstration of the detection of SiO_2 clouds will be achieved using an existing preprototype imager. The instrument would have commercial applications in remote monitoring of manufacturing plants or waste remediation sites for hazardous chemical and aerosol emissions and in manufacturing process monitoring as a high speed temperature sensor.

DOE Grant No. DE-FG05-94ER81759
Amount: \$75,000

The goals of this project are to develop a method to rapidly generate gene probes to identify and monitor indigenous degradative microorganisms at polluted sites and degradative organisms added to augment natural populations, and to use the probes as a predictive tool for determining degradative potential

for selecting appropriate treatment conditions. The probes will also be used to assess the progress of treatment so timely adjustments can be made to maintain optimum treatment performance. The probes will be generated by using a novel arbitrarily primed polymerase chain reaction (AP-PCR) protocol that generates a "fingerprint" of degradative strains, and allows the selection of unique DNA fragments which will function as sub-strain specific probes. The AP-PCR probes allow the detection of individual strains without relying on homology to probes based on already-cloned degradative genes, thereby allowing detection of strains with novel degradative genes or strains not detected by "standard probes". Gene probing will be performed in conjunction with the use of novel DNA extraction and fractionation protocols which separate the community DNA based on its % G+C. These protocols allow the analysis of the total microbial community including non-culturable cells, and improve the sensitivity of detecting specific organisms. They also provide a mechanism for monitoring gross changes in the microbial community in response to environmental changes, thereby allowing adjustment of treatment conditions to optimize performance.

Anticipated Results/Potential Commercial Applications as described by the awardee: The results of this work should provide a mechanism to monitor the progress of, and optimize, in situ bioremediation efforts. These methods would allow for reduction in costs of in situ bioremediation by improving performance (increased rates and improved efficiency) of treatment systems, thereby improving the commercial advantage of biological solutions to waste treatment. They may ultimately lead to the development of commercial kits for estimating degradative potential of sites to determine best treatment strategies, and to monitor the progress and efficiency of treatment.

Research on in-situ remediation of subsurface pollution and hazardous wastes includes studies on the identification of bacteria in such sites. The origins, distributions, and relationships to environmental conditions are facilitated by learning the identity of the bacteria present in the sites. Highly desirable would be the identification of organisms directly from the soil without the necessity of getting the organisms into pure culture. Phase I will explore the use of supercritical fluid extraction of bacterial lipids directly from soil samples, followed by derivitization and gas chromatographic analysis. Use of the electron capture detector with fluoro esters will provide enhanced sensitivity for detection of relatively small numbers of organisms. The resulting complex mixture of fatty acids will be studied using biomarker fatty acids (compounds unique to a limited class of organisms) to identify major species components of the mixed population. Another algorithm will then use the biomarker information to set up a matrix of possible species combinations and compare the results of the matrix to the complex profile. This should make possible reasonable estimates of the percentage composition of each of the major bacterial species in a complex consortium.

Anticipated Results/Potential Commercial Applications as described by the awardee: The major anticipated result is a technique for identification of bacteria directly from environmental samples without overnight culturing. In addition to applications in the bioremediation area, the research should have clinical applications for detection of bacteria directly from tissues. It might also find utility in pharmaceutical applications in identification of mixed cultures in microbiology quality control.

Bacterial Identification from Environmental Samples by Phospholipid Fatty Acid Analysis--
MIDI, Inc., 115 Barksdale Professional Drive,
Newark, DE 19711; (302) 737-4297
Dr. Myron Sasser, Principal Investigator
Dr. Myron Sasser, Business Official
DOE Grant No. DE-FG05-94ER81812
Amount: \$70,795

HEALTH EFFECTS

147

An Automated DNA Probing, Sizing, and Sequencing System--Gamera Bioscience Corporation, 30 Memorial Drive, Cambridge, MA 02142; (617) 441-1080

Dr. Alec Mian, Principal Investigator

Dr. Alec Mian, Business Official

DOE Grant No. DE-FG02-94ER81769

Amount: \$74,948

Over the last decade, research in human molecular genetics, fueled by a variety of technological innovations, has undergone enormous advances. Gel electrophoresis, Southern hybridizations, DNA sequencing, and polymerase chain reaction are examples of techniques that have greatly facilitated the discovery and characterization of disease-causing DNA polymorphisms. Unfortunately, the transfer of these technologies from research laboratories into diagnostic clinical laboratories has been difficult, mainly for two reasons. First, many of the above-mentioned techniques, especially gel electrophoresis and Southern hybridizations, require skilled personnel and are difficult if not impossible to automate. Second, the technological agendas for research laboratories can be very different from diagnostic laboratories; the former is concerned with discovery and technological flexibility, and the latter with dedicated, automated, high-throughput systems. This project is concerned with a novel gel-free detection system that seeks to unite some of the more cumbersome diagnostic techniques into a single, simple, automated instrument. The technology will allow (1) sizing of small (<200 - 300 bases) DNA fragments, (2) accurate and sensitive probing and detection of amplified or genomic DNA sequences, and (3) sequencing of short stretches of DNA (20 - 50 bases) such as sequence tag sites (STSs). Although such a technology may only have limited application in research laboratories (because of short DNA sizing and sequencing capacities), it is especially attractive to diagnostic laboratories: the sizing and sequencing capacities are sufficient for the detection of polymorphisms, and it is rapid and easily automated for high throughput. Phase I will characterize the parameters and feasibility of the DNA probing, sizing, and sequencing aspects of the

technology. In Phase II, automation and scale-up to 96-well format will be proposed.

Anticipated Results/Potential Commercial Applications as described by the awardee: The anticipated result of this project is a system that will analyze short polymorphic stretches of DNA by direct sizing, probing, and/or DNA sequencing. The anticipated ease of use, rapid run times, and high throughput of such an instrument should find ready commercial application in clinical diagnostic laboratories involved in the screening of human polymorphisms and genetic diseases. In addition, the instrument's capacity to merge presently disparate genetic diagnostic technologies is expected to accelerate consolidation, standardization, and acceptance of human genetic diagnostic tests.

148

Signal Amplification for Specific Nucleic Acid Detection--Third Wave Technologies, Inc., 2800 South Fish Hatchery Road, Madison, WI 53711-5399; (608) 273-8933

Ms. Mary Ann D. Brow, Principal Investigator

Dr. Lance Fors, Business Official

DOE Grant No. DE-FG02-94ER81891

Amount: \$75,000

This project will attempt to commercialize a novel, high-speed, and automatable DNA and RNA diagnostic technology for the specific detection of nucleic acid sequence changes associated with genetic diseases. This technology is based on the discovery that the 5' nuclease of several thermostable DNA polymerases can be engineered to direct cleavage of DNA or RNA at one and only one location, allowing the development of a very fast, sensitive, specific, and isothermal cleavage-based detection technology. Phase I should show that the signal released from the recognition of the target sequence can be propagated through an amplifying cleavage cascade. This will entail optimization of conditions for cleavage, further characterization of the enzyme activity, and testing of the molecules involved in the amplification cascade. Phase II would complete the development of this broad-based nucleic acid

detection technology that can play a significant role in making cost-effective, large-scale early detection, diagnosis, and monitoring of a wide variety of diseases a reality.

Anticipated Results/Potential Commercial Applications as described by the awardee: The fast,

simple, specific, sensitive, reliable and user-friendly technology for the detection of DNA and RNA sequences and sequence changes developed in this project will significantly increase the speed and decrease the cost of detecting, diagnosing, and monitoring a wide variety of diseases and disorders.

HUMAN GENOME

149

Estimating, Encoding, and Utilizing Uncertainties in Sequence Data--Computational Biosciences, Inc., P.O. Box 2090, Ann Arbor, MI 48106; (313) 426-9050

Mr. John Hartman, Principal Investigator

Mr. John Hartman, Business Official

DOE Grant No. DE-FG02-94ER81729

Amount: \$74,999

Among the stated goals of the Human Genome project is a dramatic improvement in DNA sequencing technologies and corresponding reduction in cost per finished base sequenced. Relatively little attention, however, has been given to the problem of assuring the quality of the rising tide of mass-produced data as genomic sequencing becomes ever more automated and production-oriented. At a very minimum, it will be incumbent on the producers of sequence data to provide information regarding its reliability, preferably for each sequenced base. This will require that such information be estimated as automatically and as inexpensively as is the sequence data itself. This Phase I project will address this issue by achieving the following broad objectives: (1) approaches to the estimation of base-specific uncertainty information from the outputs of automated sequencing machines will be studied and evaluated, (2) methods for compactly encoding, storing, viewing, and manipulating this information will be implemented and evaluated, (3) a fragment assembly algorithm will be designed that utilizes this information for input fragments and generates consistent estimates for finished assemblies, and (4) a variety of sequence analysis algorithms will be adapted to make optimal use of uncertainty information where it is available.

Anticipated Results/Potential Commercial Applications as described by the awardee: The result of this research will be a revision of software that is analytically robust with respect to uncertainties in DNA and protein sequences generally, and includes modules supporting (1) the estimation of these uncertainties from primary data, (2) the consistent management of uncertainty data through fragment assembly and experimental corroboration, and (3) the storage, display, reporting, and dissemination of uncertainty data. Expected benefits include better reliability of sequence data, longer reads with existing sequencing technologies, and more robust handling of sequencing errors and uncertainties by analytical software.

150

Low Cost Automated Preparation of Plasmid, Cosmid, and Yeast DNA--MacConnell Research Corporation, 11408 Sorrento Valley Road, Suite 202, San Diego, CA 92121; (619) 452-2603

Dr. William P. MacConnell, Principal Investigator

Dr. William P. MacConnell, Business Official

DOE Grant No. DE-FG03-94ER81802

Amount: \$75,000

A low cost, automated, benchtop instrument that can purify up to 24 samples of plasmid DNA simultaneously in one hour is now available. The instrument uses a form of agarose gel electrophoresis to separate the plasmid DNA and recovers it by electroelution into ~20 µl volume. The instrument has many advantages over other robotic and manual methods including the fact that it is twice as fast, at least six times less expensive, much smaller in size, easier to operate, lower in cost per sample, and it results in DNA pure enough for direct use in

fluorescent automated sequencing. In addition, the instrument has only one moving part associated with its purification process and does not have internal reagent reservoirs. The instrument process begins with bacterial culture which can be loaded directly into a disposable sample cassette in the machine. Phase I will develop a more complex instrument using the above technology which will simultaneously process 192 (2 x 96) bacterial samples in 1.5 hours and allow the purification of both cosmid and genomic DNA from yeast and mammalian cells in quantities of 3 to 5 micrograms per cassette lane. The goal will be to obtain DNA of sufficient purity for direct use in automated fluorescent and manual sequencing as well as other molecular biology protocols.

Anticipated Results/Potential Commercial Applications as described by the awardee: The planned instrument and its disposables will be directly applicable to the molecular biology supply market consisting of over 25,000 laboratories groups in the US and nearly as many in Europe and Japan combined. Automated, cost effective, small-scale preparation of DNA is of central importance to most molecular biology researchers and to the Human Genome Project where reduction in the cost and man-hours of DNA sequencing is a major goal.

151

Pedigree Software for the Presentation of Human Genome Information for Genetic Education and Counseling--Molecular Machines,

Inc., 2001 Wallace Avenue, Aptos, CA 95003; (408) 662-8706

Dr. Charles L. Manske, Principal Investigator

Mr. Timothy Popin, Business Official

DOE Grant No. DE-FG03-94ER81815

Amount: \$75,000

The information generated by the Human Genome Project requires innovative displays if the information is to be widely utilized. This project involves the development of new algorithms for the efficient layout of pedigree diagrams to display genetic information for effective visualization of genetic relationships. These algorithms will be integrated with an interactive user interface for constructing pedigrees, setting attributes of individuals in pedigrees, and performing genetic calculations. Phase I will lay a foundation for integration of pedigree graphics with other data such as electrophoresis gel image analysis, cytogenetic data, and chromosomal maps.

Anticipated Results/Potential Commercial Applications as described by the awardee: This project will develop algorithms and software to display genetic pedigrees whose elements are interactive icons associated with individuals. These icons will allow access to databases of genetic information for display or genetic calculations and will allow launching of other programs.

MEDICAL APPLICATIONS

152

Growth of Lutetium Phosphate Scintillator Crystals for Positron Emission Tomography--ALEM Associates/Radiation Monitoring Devices,
303A Commonwealth Avenue, Boston, MA 02115;
(617) 353-9581

Dr. Alexander Lempicki, Principal Investigator

Dr. Alexander Lempicki, Business Official

DOE Grant No. DE-FG02-94ER81702

Amount: \$75,000

Positron emission tomography (PET) is a powerful new tool for radiographic imaging of human organs, particularly the brain. However, most presently known scintillator materials find their application limited by deficiencies in one or more of the desired characteristics: brightness, stopping power, speed, chemical stability, and cost. Thus, the full realization of the potential of this diagnostic tool requires the development of innovative scintillator materials that are faster, brighter, and more sensitive than any that are presently available. A

new material system with great promise as a scintillation detector for PET applications has been discovered. This material, cerium-doped lutetium phosphate, offers a substantial improvement in performance over those now being used. It has high stopping power, superior light output, and rapid decay. Indeed, it is unique among currently known materials in combining superior performance in all important aspects for such application. Despite all these established advantages, however, one major development remains to be achieved before they can fulfill their destined role: a commercially viable method for fabrication. In Phase I the feasibility of applying either of two recognized technologies, Czochralski growth from the melt and traveling zone flux growth, to the practical fabrication of the requisite crystals will be assessed. Suitable specimens will then be evaluated optically, a fabrication method of choice identified, and the groundwork laid for full-scale exploitation in Phase II.

Anticipated Results/Potential Commercial Applications as described by the awardee: This project would develop a process for fabricating a demonstrably superior material into useful detector components, thereby generating a line of improved scintillators for PET applications. With a typical camera requiring thousands of crystals, it is clear that the new material could have a major commercial impact.

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Top-Seeded Solution Growth of Lutetium Phosphate from Potassium Pyrophosphate Flux--Deltronic Crystal Industries, Inc., 60 Harding Avenue, Dover, NJ 07801; (201) 361-2222
Mr. Robert Uhrin, Principal Investigator
Mr. Stuart Samuelson, Business Official
DOE Grant No. DE-FG05-94ER81737
Amount: \$74,159

New detector materials are required for the design of new and improved positron emission tomography instruments that would offer higher resolution and better sensitivity in non-invasive medical applications. Currently, bismuth germanium oxide is one of the most popular scintillator materials because of its relatively good properties and low cost. Recently, cerium-doped lutetium orthophosphate

(LOP) was shown to have exceptional promise as a scintillator material because of a light output twice that of bismuth germanium oxide and a decay time an order of magnitude shorter. Cerium-doped LOP crystals are currently produced by slowly cooling a molten solution which has an appreciable solubility for the scintillator material. Crystals produced by this method are large enough for determining fundamental properties but too small to efficiently fabricate detector crystals. A top-seeded solution growth method is planned in Phase I for producing cerium-doped LOP crystals commercially. The flux used to grow LOP crystals by slow cooling is based on lead pyrophosphate. While this material could be used to grow crystals by the top-seeded method, crucible cleaning is complicated by the necessity to dissolve the flux with strong acids. Furthermore, lead compounds have undesirable toxicological and environmental properties. Use of potassium pyrophosphate is planned as the solvent for growth of LOP by the top-seeded solution technique. This compound is very soluble in water and has a reduced toxicological and environmental sensitivity. Development of solubility data for molten solutions of LOP and potassium pyrophosphate should lead to the demonstration of feasibility for the top-seeded solution growth of this new scintillator crystal from a potassium pyrophosphate flux.

Anticipated Results/Potential Commercial Applications as described by the awardee: It is anticipated that the Phase I effort will establish the foundation for growth of high-quality single crystal LOP in a Phase II project by developing needed information on a suitable flux, solubility data, and demonstration of top-seeded solution growth. The availability of high-quality LOP crystals will lead to faster, more compact instruments for positron emission tomography. Additionally, this growth process could be used for growth of other rare earth orthophosphates for use in such applications as diode-pumped tunable lasers, optical isolators and high-power polarizers.

Low Field Magnetic Resonance Imaging with SQUIDS--Quantum Magnetics, Inc., 11578 Sorrento Valley Road, San Diego, CA 92121; (619) 481-4015
 Dr. S. Kumar, Principal Investigator
 Mr. John P. Sanders, Business Official
 DOE Grant No. DE-FG03-94ER81839
 Amount: \$74,147

Superconducting quantum interference devices (SQUIDS) are the most sensitive magnetic field detectors in existence. Recent experiments have shown that SQUIDS can be used to detect radio frequency nuclear magnetic signals. This opens up the possibility of using SQUIDS to do magnetic resonance imaging (MRI), particularly at low fields. SQUID detection would make possible (1) increased image contrast using very low applied fields, (2) enhanced sensitivity for detecting non-hydrogen nuclei, (3) systems that operate at a wide range of frequencies, and (4) low cost systems using inexpensive low field magnets. SQUID MRI systems will be cost effective with conventional low T_c (critical temperature) SQUIDS, and will be even less expensive as good high T_c SQUIDS become available. In Phase I, a design for a prototype imaging system will be specified. Part of the Phase I effort will be to show that SQUIDS can be adapted to an imaging environment of changing fields and gradients.

Anticipated Results/Potential Commercial Applications as described by the awardee: The planned research will lead to the development of a superior MRI system, particularly at low fields, which will find wide use in medicine.

A Room Temperature, Low Noise Silicon Photodiode for Positron Emission Tomography--Radiation Monitoring Devices, Inc., 44 Hunt Street, Watertown, MA 02172; (617) 926-1167
 Mr. Kanai S. Shah, Principal Investigator
 Dr. Gerald Entine, Business Official
 DOE Grant No. DE-FG02-94ER81844
 Amount: \$75,000

Positron emission tomography (PET) is a non-invasive medical imaging technique, which provides an image of a positron emitting radio pharmaceutical

and its distribution in the body on a metabolic level. At the present time, the performance of this instrument is limited by the nuclear sensors used. Researchers have developed a promising dual detector concept for generating high resolution positron emission tomographs. In this concept, a photomultiplier tube coupled to several small scintillators is the primary detector for determining the time and the energy resolution of the interaction, while small photodiodes attached to the other face of each scintillator identify the crystal that scintillated. The depth of interaction is determined by combining the signals from both the photomultiplier tube (PMT) and the photodiode. The relatively high noise in conventional p-i-n photodiodes caused by their large capacitance is limiting the performance of this promising PET concept. The goal of the Phase I project is to develop new types of low capacitance silicon photodiodes which can operate with low noise at room temperature. If the project is successful, the use of these new photodiodes in the dual detector PET concept promises to be the breakthrough needed for the construction of new generation of high resolution PET imaging systems.

Anticipated Results/Potential Commercial Applications as described by the awardee: The planned sensor would have an enormous impact on the design of PET instruments. In addition, a high performance room temperature scintillation photodetector would find many other nuclear medicine applications. This detector could also have a variety of applications in physics research, industrial testing, and radiation safety.

Production of Carbon-11-Labeled Compounds for Positron Emission Tomography with a Low Energy Accelerator--Science Research Laboratory, Inc., 15 Ward Street, Somerville, MA 02143; (617) 547-1122
 Dr. Ruth E. Shefer, Principal Investigator
 Dr. Jonah Jacob, Business Official
 DOE Grant No. DE-FG02-94ER81854
 Amount: \$74,981

A new generation of economical, compact low energy accelerators have recently become available for the production of radioisotopes for positron emission tomography (PET). This project addresses the need

for a carbon-11 (^{11}C) production target and radiochemical synthesis system for use with these new accelerators. ^{11}C -labeled biological molecules are used in a wide variety of important PET applications, including the study of receptor-based systems in the brain and heart, oxidative metabolism in tissue, and glucose metabolism. ^{11}C targets currently used with PET cyclotrons are not suitable for use at low bombarding energy. In Phase I, a new technique for the production of ^{11}C in a solid target via the $^{11}\text{B}(\text{p},\text{n})^{11}\text{C}$ nuclear reaction will be investigated. The goal of Phase I will be to develop an automated target design that provides $^{11}\text{CO}_2$ in clinically useful quantities, with high radiochemical purity, and with sufficiently high specific activity for the labeling of receptor ligands as well as acetate and glucose. In Phase II, we will couple this target to automated radiochemistry systems for conversion of the extracted activity to ^{11}C -radiopharmaceuticals commonly used in research and clinical PET studies.

Anticipated Results/Potential Commercial Applications as described by the awardee: The ^{11}C production target and chemical synthesis system developed in this program will allow the reliable, automated production of ^{11}C -radiopharmaceuticals with the new generation of economical, low energy accelerators for PET. The commercial availability of this system will speed the development of protocols for patient diagnosis and treatment monitoring with ^{11}C PET and will increase cost-effectiveness of PET in clinical practice.

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X-Ray Cadmium-Zinc-Telluride Focal Plane Arrays for Medical Imaging--Spire Corporation, One Patriots Park, Bedford, MA 01730-2396; (617) 275-6000

Dr. Rengarajan Sudharsanan, Principal Investigator
Mr. Patrick N. McDonnell, Business Official
DOE Grant No. DE-FG02-94ER81904
Amount: \$74,951

A new cadmium-zinc-telluride ($\text{Cd}(\text{Zn})\text{Te}$) linear X-ray focal plane array for scanning and staring medical imaging applications is being studied. The design is based on $\text{Cd}(\text{Zn})\text{Te}$ photodiodes, fabricated using metalorganic chemical vapor deposition (MOCVD) and advanced array processing technology. These focal plane arrays offer advantages of higher

spatial and energy resolution and better sensitivity than conventional film-phosphor and scintillator-photodiode/ photomultiplier X-ray detectors. In addition, due to increased sensitivity of these detector arrays, the required X-ray dosage to patients can be reduced. Phase I will develop a small array of $\text{Cd}(\text{Zn})\text{Te}$ photodiodes. MOCVD will grow a $\text{Cd}(\text{Zn})\text{Te}$ epitaxial layer on one side and a mercury telluride (HgTe) layer on the other side of high resistivity $\text{Cd}(\text{Zn})\text{Te}$. Titanium/aluminum layers will form a Schottky junction on the CdTe layer and HgTe will form an ohmic contact on the bulk $\text{Cd}(\text{Zn})\text{Te}$. Arrays with $100\text{ }\mu\text{m} \times 100\text{ }\mu\text{m}$ pixel size will be fabricated and tested for pixel-to-pixel uniformity. During Phase II, large arrays with smaller pixel size will be developed. In addition, a p-i-n device structure will be used to improve the performance of these detector arrays and commercialization of the technology will be pursued.

Anticipated Results/Potential Commercial Applications as described by the awardee: CdTe focal plane arrays with high spatial resolution and sensitivity will replace film-phosphor and scintillator-photodiode X-ray detectors in scanning medical imaging systems. In addition, these focal plane arrays can be used in X-ray astronomy, airport baggage scanners, and non-destructive testing.

PLASMA CONFINEMENT SYSTEMS TECHNOLOGY

158

A Continuous Cryopump/Pellet-Fabrication Apparatus for Fusion--Cryogenic Applications F, Inc., 450 Bacon Springs Lane, Clinton, TN 37716; (615) 435-5433

Dr. Christopher A. Foster, Principal Investigator

Dr. Christopher A. Foster, Business Official

DOE Grant No. DE-FG05-94ER81734

Amount: \$74,649

Fusion reactors based on the magnetic confinement of plasmas will require active fueling to replenish the deuterium/tritium escaping the plasma. Cryogenic pumps and frozen pellet injection are the most efficient means of pumping and refueling the tokamak plasma. Since the burn rate of the reactor is only a few percent, however, the exhaust fuel will have large quantities of unreacted deuterium and tritium. Since tritium is a radioactive gas it is important to limit the total tritium inventory of the reactor to a minimum. This will require rapid recycling of the tritium pumped from the reactor into the pellet fuel injection system. This project will accomplish this with a continuous cryogenic forepump which will receive the exhaust from the primary pumping system and produce high quality frozen deuterium/tritium pellets suitable for directly feeding a centrifuge pellet injector. The cryopump will thus be able to greatly reduce the tritium inventory by recycling the fuel back into the plasma within a few minutes from the time the fuel enters the pump. In addition the proposed pump/pellet fabrication apparatus consists of a single cryopanel which will both pump and produce pellets with no moving parts, thereby greatly increasing the reliability and reducing the cost of the apparatus as compared to conventional pumping and pellet fueling systems. In Phase I a small pump will be constructed which will demonstrate the capability of producing deuterium pellets, and a conceptual design of a full scale reactor system, to be constructed and tested as a Phase II effort, will be produced.

Anticipated Results/Potential Commercial Applications as described by the awardee: This work will lead to a practical cryogenic forepump which will produce frozen pellets of deuterium/ tritium. Such

an apparatus will greatly simplify a fusion reactor fuel cycle and dramatically reduce the tritium inventory and therefore improve the passive safety of future commercial fusion reactors.

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Sapphire-Metal Joining for Low-Loss Gyrotron Windows--FM Technologies, Inc., 10529-B Braddock Road, Fairfax, VA 22032; (703) 425-5111

Dr. Richard Silberglitt, Principal Investigator

Dr. Frederick M. Mako, Business Official

DOE Grant No. DE-FG05-94ER81765

Amount: \$74,983

A new technique, pulsed electron beam (PEB) joining, will be applied to the problem of joining low-loss ceramic materials used for windows in high frequency microwave devices to the metal vacuum envelope of the microwave device. The PEB technique allows selective heating of the specimen to be joined through preferential energy deposition that is controlled by a combination of the electron beam parameters and the properties of the specimen. Test specimens to be joined in Phase I will consist of sapphire plates and thin copper sheets. The microstructure of the test specimens will be examined using scanning electron microscopy, and comparisons will be made with expectations bases upon Monte Carlo computer simulations of the PEB energy deposition profile. The mechanical strength of the test specimens will then be evaluated using microindentation techniques. Based upon these data, joining parameters will be identified for Phase II test specimens that will allow determination of the properties of PEB-produced joints under conditions that simulate window designs for gyrotron oscillators.

Anticipated Results/Potential Commercial Applications as described by the awardee: High power gyrotrons are a critical component of electron cyclotron resonance heating, a preferred and promising heating method for magnetic fusion plasmas. The window is currently the single most serious mode of failure of high power gyrotrons in

recent years. This project, if successful, will provide a method for attachment of low-loss windows in gyrotron oscillators with minimal residual stress, which will greatly increase window design flexibility.

160

Economical and Reliable Niobium-Tin Conductors via Innovations in Stabilizers--IGC

Advanced Superconductors, 1875 Thomaston Avenue, Waterbury, CT 06704; (203) 753-5215

Dr. Hem C. Kanithi, Principal Investigator

Mr. B. A. Zeitlin, Business Official

DOE Grant No. DE-FG02-94ER81782

Amount: \$75,000

High critical current densities (J_c) and low AC losses are being achieved in Nb_3Sn as a result of design and/or process innovations that came about over the last decade. The so-called internal tin approach which has been the choice of US industry, has emerged in many forms; each with a novelty to address one characteristic of the conductor or another. The general approach itself involves the manufacture of two major components - 1) a composite element and 2) a stabilizer tube. The latter provides relatively large amounts of copper desirable in the wire to add stability and protection to the final superconducting device. It has to incorporate diffusion barriers such as Nb, Ta, or V to keep the tin from polluting the copper during final heat treatment. In cases of pulsed field applications, it should not react with tin forming a continuous Al₅ superconducting layer. The present method of making the stabilizer member is by tubular hot extrusion. The geometry and ductility constraints placed on the diffusion barrier material are so demanding that over the years the stabilizer manufacturing process has become a very expensive and tedious one. In order to limit total strain from billet to final wire, the stabilizer billet diameter and the restack bundle size have been reduced raising the cost materials. Since the stabilizer is a critical component both in terms of product performance and cost, IGC Advanced Superconductors proposes a program to develop reliable and significantly economical Nb_3Sn conductors by improving stabilizers. The feasibility of producing stabilizers by hot isostatic pressing (HIP), totally circumventing extrusion will be studied in Phase I. Barrier materials-Nb, Ta, and a combination of the two will

be incorporated in small stabilizers which will be further tested by co-drawing with composite materials. Mechanical and material design details and HIP parameters that are optimal will be investigated. Following the success of Phase I effort, scaled-up designs and cost details for large quantity production will be addressed.

Anticipated Results/Potential Commercial Applications as described by the awardee: The intended result of this research is the development of an economical high-rate production process for Nb_3Sn based superconductors. Simplifying the manufacturing method for stabilizers used in these conductors should increase their reliability in any device application. It is expected that a third of the present internal-tin costs can be eliminated. Applications that could benefit include magnets for fusion, future High Energy Physics accelerators, high frequency NMR spectroscopy and possibly, cryogenless MRI scanners for medical diagnostics.

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Improvement in the Loss and Critical Current Density Properties of Internal-Tin Niobium-Tin--IGC

Advanced Superconductors, 1875 Thomaston Avenue, Waterbury, CT 06704; (203) 753-5215

Dr. Eric Gregory, Principal Investigator

Mr. B. A. Zeitlin, Business Official

DOE Grant No. DE-FG02-94ER81783

Amount: \$75,000

The aim of this work is to further improve the properties of internal-tin niobium-tin (Nb_3Sn) strands for fusion applications. A conductor has been developed which meets all the HP-1 International Thermonuclear Experimental Reactor (ITER) specifications. In this project losses will be further lowered by reducing the "bridging" that occurs between neighboring filaments. In Phase I the effects of various heat treatments and tin concentrations on the critical current (J_c) and loss properties will be examined. The loss properties of the individual subelements will be compared with those of the 19 subelement assemblies at different sizes, in order to determine the absolute spacing below which coupling occurs between the first and second row of filaments and also the effects of distortion. In Phase II the data obtained in Phase I

will be used to design a subelement strand and an ideal restack array for low loss, high J_c operation.

Anticipated Results/Potential Commercial Applications as described by the awardee: This work should result in the development of an improved, low loss Nb_3Sn material for magnets to be used in high field pulsed or high ramp rate applications. At the present time, most of the demanding requirements arise in the fusion area. One such possible application would be the inner windings of the ITER central solenoid coil.

162

ANSAT - An Antenna Sheath Analysis Tool--
Lodestar Research Corporation, 2400 Central Avenue, P-5, Boulder, CO 80301; (303) 449-9691
Dr. James R. Myra, Principal Investigator
Dr. Richard E. Aamodt, Business Official
DOE Grant No. DE-FG05-94ER81799
Amount: \$75,000

The goal of the Phase I research is to develop a preliminary version of antenna sheath analysis tool (ANSAT), a post-processor for the ARGUS code. ARGUS is an existing full wave electromagnetic code which can be used to determine the electromagnetic fields produced by ICRF (ion cyclotron range of frequencies) antennas in the context of ion-cyclotron heating of fusion plasmas. The ANSAT code will use the output from ARGUS to calculate radio frequency (rf)-sheath driving voltages on the Faraday shield of an antenna. In Phase I, critical aspects of the physics and code development will be examined in order to assess the prospects for developing a complete sheath analysis tool in Phase II. A preliminary version of the code will be developed in Phase I to show how the rf sheaths driving voltages can be calculated and employed to assess the strengths and weaknesses of an antenna design with respect to critical voltage handling and edge plasma interaction issues. These issues include hot spots on the screen, weak points with regard to breakdown, ICRF-convective cells, power dissipated in the sheaths, and the influx of impurities resulting from rf-driven sputtering processes at the Faraday shield.

Anticipated Results/Potential Commercial Applications as described by the awardee: If successful, the Phases I to III research and develop-

ment projects will result in a user friendly post-processing code or suite of codes that will support the design of ICRF antennas operating in fusion plasmas. The codes will provide a unique capability to assess antenna designs for important sheath related phenomena to a degree that is not presently available. Antenna designs will be an important part of upcoming plans for both the Tokamak Physics Experiment (TPX) and International Thermonuclear Experimental Reactor (ITER) tokamaks, as well as possibly IGNITOR, Wendelstein VII-X, and Faraday screenless operation on Joint European Torus (JET). The availability of a sheath antenna design tool will be both timely and marketable to the Federal Government and/or the joint central team of ITER, as well as to the European and possible the Japanese fusion communities.

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An Innovative Technique to Bond One Dimensional Carbon-Carbon Composites to Dispersion Strengthened Copper--Materials and Electrochemical Research Corporation, 7960 South Kolb Road, Tucson, AZ 85706; (602) 574-1980
Dr. S. Guha, Principal Investigator
Dr. R. O. Loutfy, Business Official
DOE Grant No. DE-FG02-94ER81804
Amount: \$75,000

One dimensional carbon-carbon (C-C) composites are considered as candidate tile materials for diverter applications due to their high thermal conductivity. Unfortunately, such composites also suffer from extremely poor cross-fiber tensile strength. The problem of bonding dispersive strengthened copper (Cu) tube, with and without soft oxygen-free high conductivity (OFHC) Cu interlayers, has been analyzed by researchers elsewhere who concluded that, although OFHC Cu layers were beneficial in reducing the stresses, the magnitude of stresses in the C-C composite was still high enough to crack the C-C composite. By contrast, an innovative solution is suggested which will eliminate the coefficient of thermal expansion (CTE) mismatch in the cross-fiber direction and simultaneously reduce the CTE mismatch along the length of the fiber. This is expected to reduce the stresses in the C-C composite to the point that they are below the failure strength of the composite. An attendant benefit of this approach is that the thermal conductivity of the tube

will also be increased. The feasibility of this concept will be investigated in Phase I by using numerical analysis and a unique composite processing technique.

Anticipated Results/Potential Commercial Applications as described by the awardee: In addition to being directly useful to fusion reactor research, which could supply the nation with a source of cheap energy in the future, other potential applications for this technology would be in the automobile and aerospace industries where joining of dissimilar materials such as ceramics to metals and composites is desired.

164

A Multi-Megawatt Millimeter-Wave Source for Plasma Heating and Control--Omega-P, Inc., 2008 Yale Station, New Haven, CT 06520; (203) 458-1144
Dr. Jay L. Hirshfield, Principal Investigator
Mr. George P. Trahan, Business Official
DOE Grant No. DE-FG05-94ER81823
Amount: \$75,000

This project is investigating the feasibility of gyro-harmonic conversion using a spatiotemporally modulated electron beam for efficient generation of multi-megawatt millimeter wavelength radiation for electron cyclotron resonance heating (ECRH) plasma heating and control. Feasibility hinges on demonstration of reasonable high harmonic conversion efficiency and suppression of competing modes. Previous theoretical work has shown high efficient fifth harmonic conversion at 94 GHz, producing megawatt-level power. The nonlinear analysis and particle simulations will be extended to 13th and higher harmonics during Phase I to obtain the design parameters of a harmonic converter for the production of power at 140 GHz and above using an X-band (8 to 12 GHz) rf driver. Methods to inhibit power flow to competing converter modes will be explored. Successful results of the Phase I study are expected to lead to designs for proof-of-principle experiments to be carried out during Phase II.

Anticipated Results/Potential Commercial Applications as described by the awardee: Successful Phase I designs and Phase II proof-of-principle experiments can establish an alternative to the gyrotron for millimeter-wave ECRH. Other

commercial applications for such a source exist in materials processing, waste disposal, and advanced particle accelerators.

165

Advanced Low-Stress Brazing of Plasma-Facing Fusion Components with High Energy Electron Beams--Science Research Laboratory, Inc., 15 Ward Street, Somerville, MA 02143; (617) 547-1122
Dr. Daniel L. Goodman, Principal Investigator
Dr. Jonah Jacob, Business Official
DOE Grant No. DE-FG02-94ER81857
Amount: \$73,994

The use of high energy ($E \sim 2$ to 19 MeV) electron beams (HEEB) at high average power ($P \sim 50$ kW to 1 MW) allows compression annealed pyrolytic graphite (CAPG) and carbon-carbon (CC) composite components to be joined to metallic substrates without the high residual stresses that accompany conventional brazing. Reliable brazing of CAPG and CC to copper alloys is necessary to fabricate plasma limiters and diverters for use in a next large fusion reactor. HEEB joining utilizes deep-penetration volumetric heating to preferentially melt a thin, high-Z braze alloy interlayer. The localized power deposition raises the graphite and interlayer temperatures without heating of the metallic substrate. The process eliminates the substrate cooling step and the residual stresses and braze failures caused by thermal expansion mismatch. HEEB brazing with induction linacs is a high-throughput process, which will allow fabrication of a diverter composed of hundreds of thousands of tiles at low unit cost. A new generation of pulsed induction linear accelerators has been developed which allow reliable, cost efficient production of high average power electron beams with the necessary parameters for carbon brazing. A unique feature of these accelerators is the high repetition rate (>5000 pps) all-solid-state pulsed power drivers which make these accelerators scalable to MW power levels at an electron beam cost of \$2 to 3/Watt. The induction accelerator technology is consistent with the power densities (1 to 5 kW/cm²) and beam energies (2 to 10 MeV) required for low-stress brazing. Preliminary experiments in Phase I will demonstrate low-stress joining and determine joint properties. Process

optimization and the fabrication of graphite and CC first-wall limiter prototypes are planned for Phase II.

Anticipated Results/Potential Commercial Applications as described by the awardee: In addition to the fusion reactor application, the ability to reliably braze graphites and carbon-carbon composites to metals is needed for high, medium, and low temperature commercial applications. High temperature (>1000°C) applications include engine components and heat exchangers for advanced vehicles (National Air Space Plane, High Speed Civilian Transport). Aerospace structures and heat dissipative planes in electronic components could also benefit from this technology.

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Ductile Joining of Beryllium to Copper--Surmet Corporation, 33 B Street, Burlington, MA 01803; (617) 272-3250

Dr. Suri A. Sastri, Principal Investigator
Dr. Suri A. Sastri, Business Official
DOE Grant No. DE-FG02-94ER81875
Amount: \$75,000

Beryllium appears to be the choice for plasma facing components of the high energy fusion reactor International Experimental Thermnuclear Reactor (ITER) design. Current design heat flux conditions for the ITER are formidable and must be dealt with safely and reliably. Components such as the divertor, as well as others, must be actively cooled. This requirement makes the development of successful methods for joining of beryllium to copper a critical issue in the fusion reactor development programs. Even though various approaches have been advanced for the joining of beryllium to itself and to other metals, the joining technology currently available cannot be used in view of the special requirements imposed by the fusion reactor environment. Beryllium is an extremely reactive metal and forms brittle intermetallic compounds when in metallurgical contact with most metals. There is also the high reactivity with oxygen resulting in the development of a tenacious oxide skin that makes wetting or diffusion bonding very difficult without extremely careful surface preparation techniques. The need for a ductile joint in the case of brazing beryllium cannot be over emphasized. An innovative surface treatment

procedure for beryllium is planned that will facilitate its brazing to copper using braze alloys with either high or low melting temperatures. The technique involves considerations of metallurgical compatibility and thin film diffusion barrier concepts.

Anticipated Results/Potential Commercial Applications as described by the awardee: Beryllium is an extremely important structural material with unique properties. The modulus to density ratio of beryllium is at least six times higher than common high performance engineering materials. The ability to successfully braze join beryllium without embrittlement is important not only for the fusion reactor application but also in the fabrication of lightweight and exceptionally stiff components for aerospace applications.

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Joining of Aluminum to Carbon-Carbon Composites for Fusion Reactor Applications--Surmet Corporation, 33 B Street, Burlington, MA 01803; (617) 272-3250

Dr. Suri A. Sastri, Principal Investigator
Dr. Suri A. Sastri, Business Official
DOE Grant No. DE-FG02-94ER81877
Amount: \$75,000

The joining technologies currently available for joining metals to carbon-carbon (C-C) composites are not entirely satisfactory for fusion reactor applications for many reasons. Active braze alloys containing reactive metals that wet the carbon by forming carbides have been the accepted method used commonly to make braze joints on C-C and graphites. Such use of active braze alloys which contain strong carbide formers often results in the tendency to produce weak joints with braze metal flowing to places not desired and yet not going to places where it is needed. The problem of joining C-C to aluminum (Al) metal is especially difficult because of the low melting point of Al, 660°C, and the large difference in coefficient of thermal expansion between Al and C-C composites. A high purity version of the low melting eutectic alloy of Al and ~12 wt. % silicon, melting near 600°C can be used to join Al, but it is not compatible with C-C materials. In Phase I the feasibility of successfully braze joining C-C test coupons to Al for fusion reactor applications will be evaluated by using a

special surface preparation and infiltration technique that replaces the C-C surface with a copper surface which then can be brazed to Al.

Anticipated Results/Potential Commercial Applications as described by the awardee: Joining of C-C to metals is an issue that impacts not only

fusion programs but also many advanced materials programs currently sponsored at the national laboratories and in industry. Companies that produce C-C composites have expressed an interest in this technology. The successful development of this novel braze technology for C-C should open a host of new applications for this important material.

FUSION ENERGY SYSTEMS

168

A Feasibility Study to Correlate Vanadium (Chromium, Titanium) Alloy Weld Strength with Weld Chemistry--Charles Evans and Associates, 301 Chesapeake Drive, Redwood City, CA 94063; (415) 369-4567

Mr. Charles J. Hitzman, Principal Investigator

Mr. James E. Plank, Business Official

DOE Grant No. DE-FG03-94ER81726

Amount: \$74,910

Vanadium (V) alloys are prime candidate materials for first wall and blanket structures in fusion reactors. However, V welds are often embrittled by the incorporation of oxygen (O), nitrogen (N), and hydrogen (H) into the weld structure. This Phase I research will determine the feasibility of correlating O, N, and H concentrations in V alloy welds with weld strength. Welds in V (chromium (Cr), titanium (Ti)) alloys will be evaluated in this feasibility research, and gas-tungsten arc welds will be prepared in different O, N, and H gas environments in order to produce a large sampling of possible weld chemistries. Hardness and tensile elongation tests will be performed on sets of welds produced under approximately 10 weld conditions. Chemical analysis of these different welds will be performed using state-of-the-art materials analysis techniques such as secondary ion mass spectrometry (SIMS), Auger electron spectroscopy (AES) and scanning electron microscopy/energy dispersive spectroscopy (SEM/EDS). These three techniques combine high elemental detection sensitivity (SIMS) with high spatial resolution analysis (AES). In addition, SEM/EDS can produce rapid elemental surveys of a sample surface. SIMS analyses of weld cross-sections will determine the concentration range of O, N, and

H contaminants. If O and N are present at sufficiently high concentration (~1% atomic), AES and SEM/EDS analyses will be performed to determine quantitative O and N concentrations. SIMS analyses will be performed, and the intensity, lateral, and in-depth distribution of these contaminants will be measured. SIMS relative ion intensities, e.g. O/V, N/V and H/V, will be evaluated and correlations between these relative intensities and the weld strength determined. Techniques such as pattern recognition and neural networks will also be applied to these data to produce correlations between more complex sets of variables. Ion implant standards of ^{18}O , ^{15}N and ^2H will be prepared in order to assess the quantitative capabilities of SIMS in analysis of this metal alloy system. This research will lead to a better definition of the chemistry of V(Cr,Ti) welds and the importance of O, N, and H to weld strength. The Phase I results will determine the approximate levels of O, N, and H introduced for a range of weld conditions, and these data will set the necessary detection sensitivity for innovative, non-destructive weld integrity monitors.

Anticipated Results/Potential Commercial Applications as described by the awardee: The analytical results produced from Phases I and II will determine the pertinent correlations between V alloy weld strength and the chemical composition of the weld. Phase II will also explore methods of non-destructively testing the chemistry of these welds. This Phase II result could lead to routine methods of preparing strong, non-brittle welds in V alloys used in nuclear fusion applications. This development will provide better methods of constructing future fusion reactors. In addition, this research could produce a non-destructive, transportable weld tester which is

sensitive to O, N, and possible H concentration in welds.

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A Multilayer Silicon Carbide Fiber Coating for Toughened, Neutron Radiation-Resistant Silicon Carbide/Silicon Carbide Composites--

Hyper-Therm, Inc., 18411 Gothard Street, Units B & C, Huntington Beach, CA 92648; (714) 375-4085

Dr. Robert J. Shinavski, Principal Investigator

Mr. Wayne S. Steffier, Business Official

DOE Grant No. DE-FG03-94ER81778

Amount: \$72,057

Silicon carbide (SiC) has been identified as a promising material for fusion energy applications because of its low activation, low decay heat, and outstanding high-temperature mechanical properties. Continuous SiC fiber-reinforced SiC-matrix composites (SiC/SiC) are of particular interest because of their relatively high strength and toughness compared to that of monolithic SiC. Currently available fiber coatings such as carbon and boron nitride have demonstrated the desired mechanical characteristics necessary to promote high composite strength and toughness. However, the utility of these materials is severely limited by their susceptibility to mechanical degradation when exposed to neutron irradiation. This limitation is due to the dimensional and microstructural instability of the fiber coating as a result of radiation exposure. SiC/SiC composites exhibiting high tensile strength and fracture toughness were developed incorporating an engineered SiC fiber coating system. By methods of chemical vapor infiltration (CVI), SiC/SiC composites, toughened by an unbonded multilayer SiC fiber coating, were produced and evaluated. Comparison of the tensile test results was made with that of a baseline state-of-the-art SiC/SiC composite system employing an optimized pyrolytic carbon (PyC) fiber coating. Results indicate that the multilayer SiC fiber coating emulates the desirable mechanical attributes of PyC necessary to impart high composite strength and toughness, and may possess the desired properties for increased neutron radiation resistance. The objective of this Phase I project is to investigate the feasibility of optimizing the multilayer SiC fiber coating system so as to maximize the strength and toughness of SiC/SiC composites for potential fusion energy applications.

Optimization will consist of evaluating the effect of the number of unbonded, uniform thickness SiC layers in the multilayer fiber coating systems. Five CVI-densified SiC/SiC composite plates incorporating one, two, four, eight, and sixteen unbonded SiC layers in their respective multilayer fiber coating systems will be produced and evaluated to determine their corresponding tensile strength and fracture toughness characteristics. An SiC/SiC composite utilizing one of the recently developed low oxygen content or stoichiometric polycrystalline SiC fibers will be produced incorporating the optimum multilayer SiC fiber coating system and evaluated to determine its durability/survivability characteristics in a neutron irradiation environment.

Anticipated Results/Potential Commercial Applications as described by the awardee: SiC-matrix composites are an enabling class of materials for first wall plasma containment, liner, and diverter components in fusion energy systems, stationary turbine and power generation components, radiant burner and heat exchanger tubes, and for a variety of thermostructural applications in aerospace propulsion combustors and nozzles, hypersonic airframe thermal protection systems, and spacecraft re-entry heatshields.

PLASMA DIAGNOSTICS

170

An Improved Heavy Ion Beam Detector for Plasma Systems--InterScience, Inc., 105 Jordan Road, Troy, NY 12180; (518) 283-7500
Dr. Jeffrey Beckstead, Principal Investigator
Dr. James T. Woo, Business Official
DOE Grant No. DE-FG02-94ER81788
Amount: \$74,793

Particle beams are commonly used for plasma diagnostics to obtain time and spatially resolved measurements of density, temperature, and space charge potential. An important application is in controlled fusion research where fluctuations in these quantities are known to have an important effect on adequate confinement of the thermonuclear plasma to realize net power output. During the last few years, beam probe measurement on experiments such as the original Texas Experimental Tokamak (TEXT) have concentrated on the characterization of the interior fluctuations, and large discrepancies still exist between theoretical predictions and experimental measurements by a variety of techniques. There is, therefore, a need for more definitive experimental measurements. To date, only two-point correlation techniques have been used on the beam probe data. The result is that only the mean wave-number, k , and the spectral width, σ_k , of the turbulence distribution, $S(k, \omega)$, can be determined; no information can be extracted on other features of the spectrum. By extending the range and number of sample volumes simultaneously recorded, a better understanding of the low- k turbulence measured by the beam probe can be achieved. This can be accomplished by placing an array of beam detectors near the plasma edge. However, to obtain the accuracy required for density fluctuations in tokamak experiments, the detectors must be sensitive to 0.1% or better in the harsh environment near the plasma edge. These measurements will provide a better understanding of tokamak plasma equilibrium, stability, and transport. Phase I will be a feasibility and optimization design study for a high-energy ion beam detector that can provide this accuracy.

Anticipated Results/Potential Commercial Applications as described by the awardee: Successful development of the detector would find widespread use in research and commercial areas. When incorporated into current heavy beam probe diagnostics, the detector arrays will result in a better understanding of the physics governing the transport processes in magnetically confined plasmas. Outside the fusion community, the detector system can be used to diagnose plasma-aided manufacturing devices where edge detectors experience high radiation exposures. In addition, high resolution detectors are required in ion implantation systems used in the microelectronics industry.

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A Rutherford Scattering Diagnostic for Ion Dynamics in Magnetically Confined Fusion--Omega-P, Inc., 2008 Yale Station, New Haven, CT 06520; (203) 458-1144
Dr. Michael A. LaPointe, Principal Investigator
Mr. George P. Trahan, Business Official
DOE Grant No. DE-FG05-94ER81822
Amount: \$75,000

The objective of this project is to study the feasibility of using Rutherford Scattering to measure ion dynamics in a magnetically confined plasma. The scattering process to be studied would utilize a neutral helium beam to scatter off the majority ions in the plasma. The scattered beam distribution provides measurement of the equilibrium ion density, temperature and flow velocity, and fluctuations of the above three qualities. The diagnostic neutral beam injector to be studied would be based on proven designs utilized at the Institute for Nuclear Physics in Novosibirsk, Russia. Designs for a multi-channel neutral particle analyzer to detect the scattered beam will also be studied.

Anticipated Results/Potential Commercial Applications as described by the awardee: A successful Phase I study would allow design specifications and costs to be determined for utilizing Rutherford scattering to directly measure ion dynamics of fusion relevant plasmas. Potential

applications are monitoring and feedback control input for large magnetic fusion devices and eventual fusion reactors, and as a species and temperature monitor for plasma based incinerators.

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A Novel Miniature Optical Chopper for Deuterium-Tritium Plasma Diagnostics--PXL, Inc., 1 - H Deer Park Drive, Monmouth Junction, NJ 08852; (908) 329-0505

Dr. Leonid Y. Polonski, Principal Investigator

Dr. Ada Suckewer, Business Official

DOE Grant No. DE-FG05-94ER81837

Amount: \$73,531

This project will develop a novel miniature optical chopper to enable fiberoptically coupled signals to be distinguished from radioluminescence generated in the fiber in a harsh radiation environment. Fiber optics are in widespread use in fusion facilities to transmit optical signals from plasmas to remote detectors that are shielded from radiation. However, the fibers are not radiation immune. Luminescence and radiation induced loss of transmission have been measured in optical fibers even at the comparatively low neutron level of present deuterium-deuterium plasmas. In deuterium-tritium plasmas, radiation effects will be two orders of magnitude higher. The planned device will enable the subtraction of radiation induced luminescence from the optical signal originating from the plasma. The device is especially suited to the restricted access and high magnetic field environment of tokamaks. The Phase I project will construct and test a prototype device. In Phase II it will be installed and optimized in a tokamak environment.

Anticipated Results/Potential Commercial Applications as described by the awardee: The work will result in the development of a compact and inexpensive optical chopper that will enable radioluminescence, generated in optical fibers in a harsh radiation environment, to be subtracted from signals carried by the fibers. By facilitating fiberoptically coupled diagnostics in high radiation environment, the device will aid in the development of commercial fusion power. It will also be ideally suitable as an inexpensive and more effective alternative to motor-driven chopper wheels for phase-locked detection of fiberoptically coupled signals.

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An X-Ray Beam Deflector for High Resolution Spectroscopy of Fusion Plasmas--Radiation Science, Inc., P.O. Box 293, Belmont, MA 02178; (617) 621-7076

Dr. Allen S. Krieger, Principal Investigator

Dr. Allen S. Krieger, Business Official

DOE Grant No. DE-FG02-94ER81845

Amount: \$75,000

Small quantities of krypton will be injected into the International Thermonuclear Experimental Reactor (ITER) as a means of radiatively cooling the edge of the plasma in order to protect the components exposed to the plasma. The krypton will be ionized to the helium-like stage under the conditions expected at the core of the ITER plasma. High resolution X-ray spectroscopy of the K lines of helium-like krypton has been suggested as a means of measuring the central ion temperature of ITER. This project will construct an X-ray optical system that will deflect the 13 keV krypton K X-rays toward the aperture of a shielded high resolution X-ray spectrometer while the paths of neutrons, gamma rays, and X-rays of other energies travel in a straight line toward an absorber. This optical system will improve the signal to noise ratio of the high resolution spectrometer in two ways. It will keep background radiation away from the position sensitive X-ray detector, and it will eliminate 6.5 keV continuum X-rays which would otherwise be diffracted in first order to overlap the krypton X-ray lines. During Phase I, the requirements for the krypton X-ray beam deflector, will be established, a preliminary design concept for the beam deflector will be developed, and the X-ray optical elements will be specified and modeled in order to estimate the improvement to be expected with this system. This information will be available in time for critical design decisions concerning ITER diagnostics. In Phase II, we will build an engineering verification prototype beam deflection system for installation at the Tokamak Physics Experiment (TPX).

Anticipated Results/Potential Commercial Applications as described by the awardee: This optical system will improve the signal to noise ratio of the high resolution krypton line spectrometer, making it possible to determine the ion temperature at the core of ITER by Doppler broadening measurements. The technique developed for this

project will demonstrate that it is possible to manipulate hard x-ray beams, and deflect them through large angles. The deflection of broad band x-ray beams will have immediate application to the shielding of other x-ray instruments exposed to adverse radiation environments. It should also find applications in synchrotron radiation research, X-ray astronomy, and ultimately in commercial X-ray technology.

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In-Situ Annealing of Radiation Damage of Optical Components in Tokamak Diagnostics--

Rockford Technology Associates, Inc., 501 South Sixth Street, Professional Arts Building, Champaign, IL 61820-5579; (217) 359-3569

Mr. Erlan G. Batyrbekov, Principal Investigator

Mr. John W. Tompkins, Business Official

DOE Grant No. DE-FG02-94ER81849

Amount: \$74,999

The harsh radiation environment presented by the D-T burning plasma in next-step tokamak fusion devices can cause severe damage to critical optical components used in research diagnostics and control instrumentation. The technical objective of Phase I is to determine the feasibility of using combined thermal/optical annealing techniques to maintain the optical quality of these components. Experimental studies, using a TRIGA research reactor to simulate the radiation environment expected in fusion devices, will determine the techniques and frequency required to carry out such annealing. The goal is to find ways to perform annealing remotely while the fusion device continues operation. This will require periodic shut-down of diagnosis channels during annealing. However, by using a well-planned schedule for the annealing and incorporating redundant channels where required, the basic diagnostics needed for safe operation could be maintained at all times. Phase I will study annealing methods for representative samples of silica and ion implanted cesium iodide. These test materials are selected for relatively good resistance to radiation damage, based on data from past studies. The experimental program would then involve a test matrix, consisting of the two samples, combined with studies of the three annealing methods (thermal, optical, and combined), and three different annealing frequencies (i.e., the interval

between annealing). Issues to be resolved include the optimal conditions (temperatures, light intensities, etc.), the duration of the annealing step, the interval between annealing treatments necessary to maintain desired transmission limits, and the effects of repeated annealing on the materials. If the feasibility of this approach is established in Phase I, studies in Phase II will be designed to develop the appropriate annealing capability for optical components in specific diagnostics for next-step fusion devices, such as the International Thermonuclear Experimental Reactor and the subsequent "demo" reactor.

Anticipated Results/Potential Commercial Applications as described by the awardee: It is anticipated that special techniques can be developed so that periodic annealing can maintain good transmission characteristics of optical materials exposed to a harsh radiation environment. This will enable the design of dependable, accurate diagnostics for fusion reactors. Other important uses include radiation hardening of "final optics" for inertial confinement fusion utilizing laser drivers, space satellite windows, solar cells, and fission reactor instrumentation. Manufacture of integrated optical/annealing units for these various applications represents a potentially significant market opportunity.

TECHNOLOGY AND INSTRUMENTATION FOR HEAVY ION FUSION ACCELERATORS

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A High-Charge-State Heavy-Ion Source--Duly Research, Inc., 1912 MacArthur Street, Rancho Palos Verdes, CA 90732; (310) 548-7123
Dr. Shmuel Eylon, Principal Investigator
Dr. David U. L. Yu, Business Official
DOE Grant No. DE-FG03-94ER81741
Amount: \$74,572

The goal of this project is the development of a heavy ion stripping technique to achieve a high charge state beam. The ion stripper proposed here could be added to existing single charge state, low emittance, high brightness ion sources. Using high charge state beams in a driver for heavy ion fusion can increase the acceleration efficiency, leading to a reduction in the driver accelerator size and cost. Several ion stripping techniques, based on the ionization of an energetic ion beam colliding with charged particle beams (electrons, ions), photon beams (lasers), and a quiescent neutral gas have been evaluated. Upon evaluation and comparison with other techniques, the neutral gas technique was selected because of its

simplicity and low cost. Phase I is a feasibility study and performance evaluation of a neutral gas ion stripper technique. A neutral gas slit stripper will be designed and tested on the Lawrence Berkeley Laboratory 2MeV, 0.8A K⁺ ion beam injector. Stripper parameters, including dimensions, gas, gas pressure, and beam parameters, including charge state distributions (stripping efficiency) and beam quality (transverse emittance) will be analyzed, verified experimentally, and optimized.

Anticipated Results/Potential Commercial Applications as described by the awardee: Results of the Phase I feasibility investigation, which examines ion stripping in a very small fraction of the ion beam, will provide design and testing criteria for the full-beam investigation in Phase II. It is anticipated that the heavy ion fusion driver-scale, high charge state ion source will provide a significant contribution to the heavy ion fusion accelerator research DOE national program. The concept of using an accelerator with a higher charge state beam will lead to a significant saving in the length and cost of the driver accelerator in a heavy ion fusion energy plant.

NUCLEAR AND HIGH ENERGY PHYSICS EDUCATIONAL DEVICES

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A Unique Educational Game with Interactive Tutorials for Learning about Accelerators, Detectors, and Particle Physics--G. H. Gillespie Associates, Inc., P.O. Box 2961, Del Mar, CA 92014; (619) 677-0076
Dr. George H. Gillespie, Principal Investigator
Dr. George H. Gillespie, Business Official
DOE Grant No. DE-FG03-94ER81768
Amount: \$74,940

An innovative multimedia game will be developed to introduce precollege students to the world of particle accelerators, particle detectors, and nuclear and elementary particle physics. The concept is a fast-moving game in which each player rides with a

group of subatomic particles through the interior of an accelerator. The game illustrates the motion of charged particles in electric and magnetic fields, simple harmonic oscillations, repulsive forces between particles with the same charge, and other fundamental physics concepts. Ultimately, as his or her beam hits its intended target, a spectrum of particles is created and the player is introduced to the elementary particles and the fundamental forces of nature. At different stages of the game, obstacles are introduced which the player must overcome, if the beam is to be successfully accelerated with adequate intensity to produce the collision event rate needed to discover a new elementary particle. The game ends with graphic exploding images of the collision events that the student's beam produces. The nuclear and elementary particles that his or her

play has created, and the detector technology used to observe them, are introduced. Videos and tutorials offer the student further information avenues. A prototype of the game will be developed, including examples of several types of interactive tutorials, during Phase I. The effectiveness of the concept as a teaching aid will be evaluated by integrating the prototype game with the classroom instruction of a physics course at the high school level.

Anticipated Results/Potential Commercial Applications as described by the awardee: This project provides an innovative and unique new approach to support secondary physics education. Precollege students will have an exciting tool with which to learn about the world of accelerators, detectors, and nuclear and particle physics in a self-paced, interactive and entertaining environment.

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The Particle Beam Optics Interactive Computer Laboratory--G. H. Gillespie Associates, Inc., P.O. Box 2961, Del Mar, CA 92014; (619) 677-0076
Dr. George H. Gillespie, Principal Investigator
Dr. George H. Gillespie, Business Official
DOE Grant No. DE-FG03-94ER81767
Amount: \$75,000

The Particle Beam Optics Interactive Computer Laboratory is a new and unique educational tool for demonstrating the physics of charged particle beams and charged particle beam optical systems. Self-paced interactive tutorials offer insight into both the principles of particle optics and the technology used in particle optics beamlines. A complete computational capability is incorporated to assist students in designing and analyzing their own particle optics systems. The Laboratory is composed of four key elements. The first is a graphical user interface shell that provides for a highly interactive learning session. The second is a knowledge database containing information on electric and magnetic optics transport elements. The knowledge database provides interactive tutorials on the fundamental physics of charged particle optics and on the technology used in particle optics hardware. The third element is a graphical construction kit that provides tools for students to interactively and visually construct optical beamlines. The final element is a charged particle optics computational

engine that computes trajectories, transports beam envelopes, and carries out similar calculations for the student designed beamlines. A modular software environment will be used for the Laboratory and during Phase I prototype modules will be written that provide examples for each of the key elements.

Anticipated Results/Potential Commercial Applications as described by the awardee: The Particle Beam Optics Interactive Computer Laboratory will provide universities and colleges with a powerful new software tool for teaching particle beam optics. Interactive tutorials and a graphical beamline construction kit are combined with an established charged particle optics computational engine to produce an innovative, self-paced education aid.

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A Multimedia Software Tutorial on Superconducting Accelerator Magnets--MJB Consulting, 1415 Country Ridge Drive, DeSoto, TX 75115; (214) 709-1957
Dr. Millicent Ball, Principal Investigator
Dr. Millicent Ball, Business Official
DOE Grant No. DE-FG05-94ER81813
Amount: \$74,959

Completion of this project will provide a multimedia software tutorial introduction to the physics and engineering concepts of superconducting magnets for high energy physics accelerators. The presentation of the material will make full use of the latest computer technology for hypertext, interactive, multimedia presentations, including video footage, sound, graphics, and animation. The target level for the tutorial is junior or senior level undergraduates. Phase I effort focuses on the design and feasibility study. The tutorial content will be developed and relevant video footage, photographs, or other material from the superconducting magnet research programs at the national laboratories will be located. Software for implementing hypertext presentations, computer animation, and interactive graphics will be evaluated. Sources and procedures for transfer of video footage to CD-ROM disks will be surveyed. Preliminary contacts will be made with undergraduate physics or engineering departments and Internet sites to locate potential test sites for Phase II. Phase II will consist of implementation

and testing of CD-ROM and Internet versions. In Phase III, the tutorial will be distributed on CD-ROM disks and Internet, for use by colleges or any interested computer users.

Anticipated Results/Potential Commercial Applications as described by the awardee: This tutorial is designed to relate undergraduate engineering and physics course work to current challenging technical research in the design of superconducting magnets for high energy physics accelerators, but it will also be useable by members of the general public who have interest in scientific subjects. The presentations will be available via CD-ROM for stand alone computers or via a federally funded server on the Internet global computer network.

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A Multimedia-Augmented Software Tutorial for the High Acceptance Recoil Polarimeter Device--Planning Systems, Inc., 7923 Jones Branch Drive, McLean, VA 22102; (703) 734-3450
Dr. E. Scott Baudhuin, Principal Investigator
Mr. Alan J. Friedman, Business Official
DOE Grant No. DE-FG05-94ER81831
Amount: \$75,000

This project will assess the feasibility of using multimedia-augmented software tutorials to support teaching the principles of experimental nuclear physics. The detector system for the photon tagging facility at the Continuous Electron Beam Accelerator Facility (CEBAF) in Newport News, Virginia is now under construction at the Nuclear Detector Laboratory of the Center for Nuclear Studies of the George Washington University. The complete tagging system will be used to demonstrate the principles of particle detection used in nuclear and high energy physics, and will relate these principles to a number of illustrative applications anticipated at CEBAF. Phase I will focus on defining the appropriate interactive multimedia-based technologies supporting state-of-the-art educational delivery systems. The feasibility of using full-motion and still frame digital video, digital audio, animation, high resolution graphics, and graphics overlays will be examined. Analyses will also be conducted of different hardware configurations that would be used to support the delivery of the multimedia-augmented

software tutorials. The analysis of delivery systems will concentrate on personal computers, CD ROM devices, and digital video solutions. Using the instructional systems development model, the project will design the tutorial, and implement the multimedia instructional design on the selected hardware for a limited set of instructional objectives as a proof of concept. The development of the multimedia-augmented software tutorial proof of concept will be accomplished with selected multimedia authoring systems and tools.

Anticipated Results/Potential Commercial Applications as described by the awardee: Phase I results should provide a proof of concept of using multimedia-augmented software tutorials to teach principles in nuclear physics. Phase II should produce a full set of software tutorials on this subject to augment senior undergraduate and early graduate level courses. These tutorials can be offered to universities via CD-ROM. Commercialization could occur via private labels or government sponsorship.

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Innovative Software for Nuclear Physics Education--Scientific Digital Visions, Inc., 954 Emory Street, San Jose, CA 95126-1853; (408) 971-4077
Ms. Jennifer A. Blanc, Principal Investigator
Dr. Craig A. Stone, Business Official
DOE Grant No. DE-FG03-94ER81858
Amount: \$74,756

Developing innovative educational software for nuclear physics will provide effective tools for advancing nuclear physics. Topics covered in nuclear courses are intriguing but often difficult to explore. Relational properties of nuclei, theoretical models, and laboratory experiments are cumbersome to apply in these settings. Textbooks provide only a limited and static view of nuclear physics. Students are limited because they cannot easily explore those experiments and facilities they will use through much of their career. Educational tools can more effectively introduce students to concepts, allow them to more thoroughly explore those topics, and facilitate the students' development in the field of nuclear physics. This Phase I project seeks to develop creative and innovative multimedia software for nuclear physics education. Key concepts in

nuclear physics can be studied using highly-interactive tutorials that integrate text, sound, animation, and computer-based videos. Some will be electronic laboratories using real or simulated data. Examples include statistics, radioactive decay, and beginning through advanced counting techniques. Electronic laboratories on nuclear models introduce the concepts of the models, along with their applications and limitations. Tutorials and laboratories are supplemented with computer-based movies using videos available through DOE laboratories, time-dependent movies created within the software, and other videos generated through the course of this project. The format may include electronically touring detectors and facilities, viewing results of experiments, or even listening to a noted scientist talk about a significant research result. Electronic bibliographies, time lines of results, and even electronic reprints of major research papers introduce students to the evolution of nuclear physics research. All tutorials and laboratories are accessible through an interactive electronic encyclopedia with an associated dictionary. Special features allow students and instructors to define pathways through the tutorials and information, and permit students to find specific references. The nuclear physics software provides instructors with educational tools for classroom use, for use in electronic nuclear physics laboratories; it is an invaluable resource for developing nuclear physicist.

Anticipated Results/Potential Commercial Applications as described by the awardee: The nuclear physics educational software developed through this project will have significant commercial value. General physics courses often give a superficial coverage to concepts in nuclear physics, because of limited expertise at many universities, and because of the difficulty in supplementing lectures with a laboratory experience. Tutorials and electronic laboratories provide those institutions with practical methods of introducing concepts of nuclear physics. The planned educational software enhances institutions with nuclear physics courses by providing innovative methods of presenting and learning key concepts.

A Multimedia Tutorial for Charged-Particle Beam Dynamics--Whistlesoft, Inc., 168 Dos Brazos, Los Alamos, NM 87544; (505) 662-7309
Dr. Richard K. Cooper, Principal Investigator
Dr. Richard R. Silbar, Business Official
DOE Grant No. DE-FG05-94ER81900
Amount: \$74,913

The objective of this project is to develop an interactive multimedia course in the physics of charged-particle beams. The level of presentation can be tailored interactively to the knowledge and ability level of the individual pupil, much as the skill level of a video game can be chosen. The student will interact strongly with the teaching program, at his or her own pace. The target market includes high school science students (e.g. advanced placement physics students), college science students, graduate students, and non-expert scientists and engineers interested in the details of accelerators and charged-particle beams. In Phase I, in addition to developing several sample learning modules, the feasibility of linking together all the elements of the multimedia tutorial will be explored. The best way of branching between different skill levels of exposition and making effective transitions between textual displays, graphical displays, and videos, possibly with accompanying sound will have to be determined. The innovative aspect of the development is to learn how to integrate a number of interactive, multimedia tools for the efficient teaching of charged-particle dynamics. The eventual product resulting from this research and development will be a computer tutorial that runs on Microsoft Windows personal computers. The course would be delivered on a CD-ROM disk, together with associated student workbooks and a teacher's manual. The final product would be sold to educational institutions and individuals at a cost small enough (\$500 or less) to allow for a large volume of sales. Toward the end of Phase I preliminary meetings with potential publishers of this software will be held.

Anticipated Results/Potential Commercial Applications as described by the awardee: The tutorial to be developed should complement, and perhaps even replace, existing classroom texts. The wider student audience that is targeted would tap a significantly larger market than has previously been

addressed. Success in developing these techniques for beam optics could produce many commercial

opportunities for developing tutorials in other technical subjects.

TECHNOLOGY AND INSTRUMENTATION FOR HIGH ENERGY ACCELERATORS

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An Inexpensive High-Current Betatron--Adelphi Technology, Inc., 2181 Park Boulevard, Palo Alto, CA 94306; (415) 328-7337

Dr. Melvin A. Piestrup, Principal Investigator

Dr. David G. Boyers, Business Official

DOE Grant No. DE-FG03-94ER81693

Amount: \$74,992

The objective of this project is to employ the betatron principle to produce an inexpensive electron accelerator capable of producing 20-50 MeV electrons with good beam quality and high-average currents of up to 5-50 μ A. In conventional betatrons which have been in existence for over 50 years, eddy-current losses in the iron limit the operating frequency, thus limiting the maximum energy and current. The use of high-frequency magnetic materials is planned so that driving frequencies of up to a few kHz may be possible, thereby permitting substantially higher average currents. As proof of principle, under Phase I an inexpensive (<\$0.2 million), moderate-energy (25 MeV), high-average-current (8 μ A) betatron will be designed. The following is also planned: determination of the orbit dynamics at high repetition frequencies; determination of the pole shapes, pole gap, orbit radius, and electron-beam emittance; design of the injection system utilizing orbit contraction/expansion coils and determination of an optimum gun size; design of the extraction system with orbit contraction/expansion coils and a magnetic shunt; and determination of the power supply reactive power and dissipative power requirements. A detailed cost estimate will be prepared with information from vendors to confirm that the cost is moderate and that the high frequency betatron can be a competitor to RF linacs in the commercial marketplace.

Anticipated Results/Potential Commercial Applications as described by the awardee: A compact

inexpensive electron source for cancer therapy has obvious benefits of making this therapy more accessible and reducing health care costs. Successful use of the betatron principle for other inexpensive accelerators could also provide for the widespread development of bremsstrahlung, transition, parametric, and channeling radiators. Thus a variety of high-intensity, monochromatic and quasi-monochromatic sources would become available for industrial, medical and military uses.

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A High-Yield and Low-Emittance Positron Source from Coherent Laser-Electron Collisions--Duly Research, Inc., 1912 MacArthur Street, Rancho Palos Verdes, CA 90732; (310) 548-7123

Dr. David U. L. Yu, Principal Investigator

Dr. David U. L. Yu, Business Official

DOE Grant No. DE-FG03-94ER81740

Amount: \$74,953

A novel high-yield positron source based on coherent pair creation from the collision of a high power laser beam with a high energy electron beam is planned for this project. The laser-produced positrons have a low transverse emittance and a narrow spectrum, peaking at an energy much below the primary electron beam energy. Spin dependent transverse forces on the created pair provide a natural polarization separation, which can be utilized to produce polarized positrons. The source does not use a solid target, thus avoiding problems associated with the conventional Bethe-Heitler pair creation process. Phase I will develop analytic and numerical tools to simulate the behavior of this promising positron source. These tools will incorporate fundamental physical processes such as spin dependent and quantum effects, the effect of the laser on the motion of primary beam and pair

produced particles, shower evolution in the laser background, and spatial and temporal variation of the laser fields. Phase I also includes a study of laser optics and mirror design to maximize collision rate. Research results will be used to establish the feasibility of the new positron source, and will be invaluable in the design of a positron extractor in Phase II.

Anticipated Results/Potential Commercial Applications as described by the awardee: The planned high-yield, low-emittance positron source will reduce the systems cost and complexity in achieving the high luminosity required in future linear colliders. It can also produce copious polarized positrons useful for high energy physics experiments.

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An Electron-Beam "Gatling Gun" for Frequency Multiplying in Microwave Generators--FM Technologies, Inc., 10529-B Braddock Road, Fairfax, VA 22032; (703) 425-5111

Dr. Frederick M. Mako, Principal Investigator

Dr. Frederick M. Mako, Business Official

DOE Grant No. DE-FG05-94ER81766

Amount: \$74,978

A high current, micro-pulse electron source is planned for microwave frequency multiplying. The device utilizes a rotating transverse magnetic (TM_{110}) cavity mode to generate a series of azimuthally distributed bunched electron pulses and is therefore similar to a "Gatling gun". Each azimuthal electron beam pulses time by T/n where T is the radio frequency (rf) period of the rotating mode and n is the number of azimuthal beam pulses created. The bunch pulse length is small compared to the separation time T/n . These electron pulses are transmitted through one wall of the cavity (e.g., by a screen), post-accelerated, and focused electrically and magnetically into an output cavity tuned to an integer multiple of the frequency of the input cavity. As an example, four azimuthal electron pulses from an input cavity driven at 2.5 GHz operating in the TM_{110} rotating mode were considered. The output cavity was selected and confirmed to be resonant at 10 GHz for the transverse magnetic (TM_{040}) mode. The concept of producing one high-current-density azimuthal electron bunch has been studied

extensively. In a detailed study of this process, including space charge and emittance, the parameters necessary to make use of the phenomenon to produce a micro-pulsed electron beam were determined. It was shown from self-consistent analytic theory and 2-D particle-in-cell simulations that the current density scales with frequency cubed. This device appears to be capable of high currents ($>kA$) and short pulses (psec). Applications for this device are primarily rf generation in the 10 to 20 GHz region, and, in particular, for the next generation of linear colliders. An rf source point design was performed utilizing the Gatling micro-pulse gun. It appears that an output rf power of 100 MW at 11.4 GHz with 61 percent system efficiency is achievable. Phase I is aimed at a detailed analysis to establish credible estimates of power, efficiency, gain, and other key parameters.

Anticipated Results/Potential Commercial Applications as described by the awardee: If successful, this "Gatling" high current, micro-pulse electron gun should provide a high peak power, multi-kiloampere, picosecond-long electron source which is suitable for high power, high frequency rf generators. Of particular interest are 10 to 20 GHz rf generators for the next linear colliders or super-power nanosecond radar.

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A Radio Frequency Chopped, Low Emittance High Voltage Electron Source for a 30 MeV, Picosecond Bunch, High Gradient 17 Gigahertz Accelerator--Haimson Research Corporation, 3350 Scott Boulevard, Building 60, Santa Clara, CA 95054-3122; (408) 988-6007

Dr. Jacob Haimson, Principal Investigator

Ms. Beverly L. Mecklenburg, Business Official

DOE Grant No. DE-FG03-94ER81774

Amount: \$74,992

This project addresses the design and development of a high resolution low emittance 30 MeV electron source for advanced accelerator research applications, and also supports 17 GHz linear collider research. Phase I investigates the feasibility of designing a demountable type 550 kV electron gun and combining it with a 17 GHz chopping and bunching system to provide a source of low emittance, fully gated radio frequency (RF) bunches of 10^8 to 10^9

electrons, having narrow momentum spread and $<2^\circ$ phase width at entry to a 17 GHz high gradient accelerator structure. Detailed beam optics analyses shall be performed with the objective of optimizing the system parameters to match the injection requirements of an exiting design 17 GHz accelerator structure, ensuring correct capture, bunch compression, and asymptotic bunch location to provide high resolution picosecond bunch ($<2^\circ$) operation over a wide range of energies up to 30 MeV. Preliminary studies of this high voltage (HV) injector concept indicate that stable injected beams, having small transverse and longitudinal phase space, can be achieved with a higher order mode spatial modulation and charge compression technique using relatively low intensity RF magnetic and electric fields requiring a total peak RF input power of only 3 or 4 kw. A further objective of Phase I is to prepare a test facility layout drawing showing a method of interfacing the proposed HV injection system with an existing high power transmitter, and a prototype 17 GHz high gradient structure, at the Massachusetts Institute of Technology Plasma Fusion Center. In Phase II, the HV injector centerline system shall be fabricated and installed in an existing radiation shielded facility, and the injection system shall be tested with the high gradient structure to investigate the characteristics of the accelerated beam and evaluate the potential of this unique 17 GHz system as a 15 to 30 MeV electron source for advanced accelerator research.

Anticipated Results/Potential Commercial Applications as described by the awardee: It is anticipated that the Phase I and II efforts will result in the design and fabrication of an RF chopped HV injection system and the high power beam testing of this system with a prototype 17 GHz, 30 MeV electron source suitable for linear collider accelerator research, for advanced accelerator research and development and free electron laser applications, and for investigation of high peak power RF generation at sub-millimeter wavelengths.

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An Efficient Higher Order Multi-Mode High Power Microwave Amplifier--Haimson Research Corporation, 3350 Scott Boulevard, Building 60, Santa Clara, CA 95054-3122; (408) 988-6007
Dr. Jacob Haimson, Principal Investigator

Ms. Beverly L. Mecklenburg, Business Official
DOE Grant No. DE-FG03-94ER81775
Amount: \$75,000

Recently published results of the six-year ongoing development of high peak power relativistic klystrons for 11.4 and 14 GHz linear colliders show that none of the tubes have demonstrated efficiencies of greater than 45%, and the majority have operated at less than 35%. In recognition of the potential limitation of these velocity modulation tubes, and because of the beneficial impact a much higher efficiency radio frequency (RF) source would have on linear collider technology, there is considerable incentive to explore new approaches for the high efficiency transfer of power from an electron beam to a coherent flux of accessible high frequency electromagnetic energy. This Phase I effort investigates a new approach for generating microwave power using spatial modulation of a high power electron beam and a novel higher order mode output cavity. The effort is directed at avoiding some of the limitations and difficulties associated with magnicons and higher harmonic (fast wave) devices by attempting to desensitize the dependence of tube efficiency on beam cross section, by operating at moderate values of transverse momentum, by aggressive suppression of multipactor, and by using a relatively large, higher order multi-mode output circuit to minimize dissipation and electric field intensities. The technique is dependent on establishing sets of higher order mode field patterns that coexist within a common boundary yet exhibit extremely high isolation (e.g., 50 to 60 dB) between contiguous and/or orthogonal modes. A further objective of the Phase I effort is to establish specific design parameters for a prototype tube, based on a suitable existing high power test facility (having an RF drive source in the range of 3 to 11.4 GHz), so that in Phase II an economical means will be available for testing the new concept.

Anticipated Results/Potential Commercial Applications as described by the awardee: It is anticipated that, if successful, the Phase I and II efforts will result in the design and prototype fabrication of a new high efficiency microwave tube suitable for linear collider research and commercial applications that would benefit from a high efficiency source of RF power.

A Novel Approach to Fabrication of Niobium-Tin Conductor with Artificial Pinning Centers--

IGC Advanced Superconductors, 1875 Thomaston Avenue, Waterbury, CT 06704; (203) 753-5215

Dr. Leszek R. Motowidlo, Principal Investigator

Mr. B. A. Zeitlin, Business Official

DOE Grant No. DE-FG02-94ER81784

Amount: \$75,000

The significance of engineered artificial pinning centers (APC) in niobium-titanium (NbTi) superconductors has been recognized world wide and today is one the most important areas of materials research in applied superconductivity. So far this approach has yielded record high critical currents (J_c) below 4 Tesla (T) field range and at some select fields almost a factor of two better, surpassing that of the conventionally optimized NbTi wires. The importance of the existence of a high performance and economical niobium-titanium (Nb₃Sn) conductor in the United States is the main justification for this Phase I effort. The Phase I work will determine whether the engineering of artificial pinning centers into Nb₃Sn wire will have significant impact on the critical current density. In addition to possible cost reduction through increased conductor performance, this Phase I project will introduce a novel design approach which will have further impact on cost reduction by eliminating the need for a diffusion barrier and therefore eliminating a separate stabilizer billet typical of today's internal tin process.

Anticipated Results/Potential Commercial Applications as described by the awardee: Significant improvement is expected in critical current density at 4.2 K at select fields, and in demonstration of the ability to achieve this increase at any field in the range 8 to 15 T. The combination of an engineered artificial pinning center Nb₃Sn conductor with a new approach for fabrication may result in a very competitive conductor for high field magnet designers in nuclear magnetic resonance devices, accelerator magnets, and the International Thermonuclear Experimental Reactor (ITER).

Improvement in the Characteristics of Ternary Niobium Titanium Tantalum Alloys--IGC

Advanced Superconductors, 1875 Thomaston Avenue, Waterbury, CT 06704; (203) 753-5215

Dr. Eric Gregory, Principal Investigator

Mr. B. A. Zeitlin, Business Official

DOE Grant No. DE-FG02-94ER81785

Amount: \$75,000

In recent years several investigations have been carried out on niobium titanium tantalum (NbTiTa) ternary alloys, and the critical current (J_c) results have not been sufficiently superior to the binary alloy at either 4.2 K or 1.8 K to warrant large scale development. Recent work, however, has shown the reasons for this. The alloys chosen did not have the highest upper critical fields (H_{c2} s) and critical temperatures (T_c s) and the heat treatments used did not appear to be ideal for maximum pinning. The Phase I project will carry out three parallel investigations: (1) A modified heat treatment schedule will be applied to the multifilamentary 25 wt. % Ta, 44 wt. % Ti alloy to improve the size and distribution of the precipitate. This should improve the J_c properties in the medium field range, (2) An alloy already selected on the basis of higher H_{c2} and T_c at 4.2 K will be processed into small billets of a multifilamentary material and its properties compared with the two alloys already fabricated in a similar manner, and (3) An alloy which shows maximum H_{c2} at 2 K and a reasonably high T_c will also be purchased and processed into monofilamentary material and the T_c and H_{c2} determined in this form. In Phase II one or two alloys which show promise will be made into full sized multifilamentary billets and their properties determined.

Anticipated Results/Potential Commercial Applications as described by the awardee: This work should result in the development of an improved material for dipole and quadrupole magnets particularly those which are expected to be used in relatively high field applications. Examples of these are low beta quadrupoles and high field dipoles for sharp bending of the beam, such as is required to direct the beam inside the accelerator ring. In many of these applications high radiation levels are encountered. The niobium tin type materials suffer degradation under these conditions whereas the ternary NbTi-based materials are relatively unaffected.

Niobium Titanium Multifilamentary Materials with Silicon in the Matrix--IGC Advanced Superconductors, 1875 Thomaston Avenue, Waterbury, CT 06704; (203) 753-5215

Dr. Eric Gregory, Principal Investigator

Mr. B. A. Zeitlin, Business Official

DOE Grant No. DE-FG02-94ER81781

Amount: \$75,000

The aim of this work is to explore further the properties of niobium titanium (NbTi) strands with matrices containing silicon (Si) for high energy physics applications. There are indications that the addition of Si to the matrix will help eliminate the Nb barrier, improve the critical current (J_c), lower the losses, and simplify the process, thus lowering the costs. This improvement is applicable to coarse and fine filament materials. Because of the very promising results and their potentially broad applications, the work will be continued. The previous work with Cu-2.5 wt. % Si and Cu-3.5 wt. % Si matrices confirmed earlier Japanese work and showed J_c 's in fine wire material which were 13% higher than those from material with an 8% barrier. It did, however, leave many unanswered questions which will be addressed in this project. Phase I will (1) obtain a better understanding of the chemical and mechanical nature of the material that is formed at the interface between the Si containing matrix and the NbTi filaments, (2) determine more about the dependence of the material's properties on the thermomechanical conditions involved in its formation and how these properties affect the drawability of the composite itself, (3) determine information on the extent to which annealing will be required in the fabrication of the composites containing Cu-2.5 wt. % Si and Cu-3.5 wt. % Si matrices, (4) ascertain if filament uniformity improves, and to what extent this results in improved J_c , and (5) obtain information on how to improve the ductility of a matrix containing both Si and manganese. In Phase II, one or two alloys which show promise will be made into full sized multifilamentary billets and their properties determined.

Anticipated Results/Potential Commercial Applications as described by the awardee: This project will ultimately result in lower cost materials with higher J_c 's and lower losses in different filament

sizes. The work will not only produce optimized material for applications where relatively large filaments can be tolerated (low beta quadrupoles, etc.) but also high J_c material for fine filament applications. This investigation will lead to materials which will have broad uses in high energy physics and very wide applications throughout the many fields where superconductors are used.

Development of a Radio Frequency Quadrupole-Focused Drift Tube Linac Structure-- Linac Systems, 115 Morene Avenue, Waxahachie, TX 75165; (214) 937-3283

Dr. Donald A. Swenson, Principal Investigator

Mrs. Barbara C. Swenson, Business Official

DOE Grant No. DE-FG03-94ER81797

Amount: \$74,976

A new linear accelerator (linac) structure will be identified and investigated in Phase I as a possible extension to the family of structures now used for acceleration of charged particle beams. A candidate structure has been identified; others may be identified in the course of the investigation. The identified structure utilizes a four-fingered geometry to produce radio frequency (rf) electric quadrupole fields to focus the beam. It resembles a drift tube linac (DTL) structure with radio frequency quadrupole (RFQ) focusing, thereby opening the possibility of higher frequency and high gradient operation. Included in the investigations of the RFQ-DTL structure will be detailed analysis of the rf fields surrounding the four-finger electrodes and the effect of those fields on the particle beams passing through them. Issues such as the rf efficiency of the structure, the stability of the fields with the structure, methods of fabrication, and methods of excitation will be addressed. Models of some critical components and/or assemblies will be fabricated for evaluation. The role of this new structure and its impact on accelerator technology will be identified.

Anticipated Results/Potential Commercial Applications as described by the awardee: It is expected that the new rf-focused linac structure, identified in Phase I and developed in Phase II of this project, will open the door to higher frequency, smaller, and more economical sources of accelerated particles and applied radiation for a whole host of

applications. Linac systems, based on these new structures in conjunction with RFQ and DTL linacs, should represent viable commercial products.

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Optimization of Beam Shaking Techniques for the Removal of Trapped Ions in Antiproton Storage Rings--Lodestar Research Corporation, 2400 Central Avenue, P-5, Boulder, CO 80301; (303) 449-9691

Dr. James R. Myra, Principal Investigator
Dr. Richard E. Aamodt, Business Official
DOE Grant No. DE-FG05-94ER81798
Amount: \$75,000

Many experiments in the frontiers of high energy physics require high luminosity as well as high energy beams. For proton-antiproton colliders, this requirement leads to the need for antiproton storage rings with smaller emittance, capable of operation at high current, and with the avoidance of catastrophic beam loss. Experiments at both CERN and Fermilab have shown that trapped ions in the antiproton accumulator (AA) are associated with limitation on these operational parameters. In this investigation, theoretical studies leading to improved methods of trapped ion removal are considered. The work will be done in collaboration with ongoing experimental work at Fermilab. The proposed scheme will optimize existing beam shaking techniques in the collective plasma regime appropriate to highly stacked beams. Phase I will develop a Vlasov theory of trapped ion equilibria, collective modes and the corresponding quasilinear (QL) theory including Landau wave-particle interaction with the trapped ions. The QL theory will yield trapped ion removal rates for the Fermilab AA as a function of collective mode amplitudes excited by beam shaking, and enable the calculation of the associated shaker power requirements. The Phase I effort will set up all necessary tools for complete identification and optimization of strategies for beam shaking. Assessment of possible scenarios (e.g., choice of collective mode, operating point for beam/trapped-ion coupling, and time sequencing of shaker power and frequency modulation) will begin in Phase I and is the major goal of Phase II, which will enable the design of an optimized shaker. Some of the techniques developed will be applicable more

generally to other accelerators with negatively charged beams.

Anticipated Results/Potential Commercial Applications as described by the awardee: This work will enable the design (of new equipment, if needed) and the operational scenarios for optimal removal of trapped ions by beam shaking techniques. It will extend previous single particle descriptions of beam shaking and trapped ion removal to the collective plasma regime appropriate to Fermilab AA operation with highly stacked beams. The end result will be a significant new tool for obtaining higher antiproton beam currents, lower beam emittance, and therefore improved performance of the accelerator as a whole.

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Superconducting Magnet Development for Compact Storage Rings--Particle Beam Lasers, Inc., 18925 Dearborn Street, Northridge, CA 91324; (818) 885-8956

Mr. Alper Garren, Principal Investigator
Mr. James J. Kolonko, Business Official
DOE Grant No. DE-FG03-94ER81826
Amount: \$75,000

This project will study and develop a type of high field superconducting magnet for positron-electron colliders, damping rings for the next linear collider, and a compact synchrotron light source with X-ray energies between 15 and 33 keV. The Phase I study will identify a superconducting magnet configuration that will satisfy the requirements of a dipole magnet of a compact storage ring based on the Vobly design and test the suitability of this magnet in a specific storage ring example. The configuration will consist of the geometry of the iron poles, the shape and locations of the coils, the required relationships of the currents in the independent coils, and the magnetic multipole functions as a function of position and currents. In addition to magnet design studies, the effort will also consider other aspects of the storage ring including the lattice, quadrupoles, vacuum, radio frequency, and injection systems. A preliminary estimate of the magnet cost and storage ring cost will be made.

Anticipated Results/Potential Commercial Applications as described by the awardee: Successful development of a high field superconducting compact

bending magnet will permit one to build small compact storage rings and hard X-ray sources for commercial and medical applications. The research could have spin-off applications in other fields such as protein crystallography, coronary angiography, mammography, and nano-technology.

193

High Quality Chemically Vapor Deposited Niobium Coatings for Superconducting Radio Frequency Cavities--Sumi Tech, Inc., 3006 McLean Court, Blacksburg, VA 24060; (703) 552-8334

Mr. Wei Tao, Principal Investigator

Mrs. Mallika D. Ilindra, Business Official

DOE Grant No. DE-FG05-94ER81871

Amount: \$75,000

Traditionally, superconducting cavities for large electron position colliders are fabricated from high purity niobium (Nb) sheets using lathe spinning and welding. These cavities suffer from the problem of thermomagnetic breakdown resulting from the relatively poor thermal conductivity of Nb at liquid helium temperatures. A more elegant and low cost solution to the breakdown problem is the use of Nb coated high purity copper (OFHC copper) superconducting cavities. However, the low field Q values of 2×10^9 at 4.2 K dropped rapidly with increasing field; for example at 3 MV/m the $Q = 3 \times 10^8$. The loss in the Q value of Nb-coated copper cavities may be attributable to the columnar grain structure, low packing density, and surface roughness of the Nb coating. In contrast to sputtering, chemical vapor deposition (CVD) will allow deposition of excellent quality films on substrates with complex geometries, such as superconducting cavities, with relative ease. In addition, CVD of Nb will possibly give dense, smooth, and fine grain Nb films, which will definitely have much better properties than those obtained by sputtering. The Phase I objectives are: a) to determine the best precursor for CVD of Nb films on copper substrates, and b) to optimize the CVD deposition conditions for Nb films on copper substrates. The Phase II objective is to build a Nb-coated copper superconducting cavity by CVD.

Anticipated Results/Potential Commercial Applications as described by the awardee: This project provides an alternative solution to the

problems encountered in superconducting cavities for large electron positron colliders. In addition to the accelerator application, Nb coatings are widely used for nuclear fuel particles.

194

Development of Niobium-Titanium-Tantalum Artificial Pinning Center Superconductors for Very High Field Applications--Supercon, Inc., 830 Boston Turnpike, Shrewsbury, MA 01545; (508) 842-0174

Dr. Jeffrey M. Seuntjens, Principal Investigator

Ms. Elaine Drew, Business Official

DOE Grant No. DE-FG02-94ER81874

Amount: \$74,954

The best enhancement in critical magnetic field (H_{c2}) for niobium titanium (NbTi) alloys has been found for a 15 to 25 wt. % ternary addition of tantalum. The precise alloy composition for the best combination of critical temperature (T_c), H_{c2} , precipitation kinetics, critical current (J_c) and ductility are still of considerable debate because NbTiTa alloys to date have not significantly outperformed binary NbTi. A process has been developed for the manufacture of NbTi composite superconductors using an artificial pinning center (APC) approach. The APC process has been extended to NbTiTa material, and model conductors show an adequate ductility and similar J_c to binary APC composites. Phase I will work to establish the best raw material configuration as well as the thermal and mechanical processes in model APC NbTiTa superconductor material. The Phase I and the anticipated Phase II efforts will complement and build upon the existing ternary conductor research and could result in a proven commercial process for ternary APC conductor. Ternary APC conductors have greater potential for higher J_c at optimal compositions than ternary approaches using melted alloy.

Anticipated Results/Potential Commercial Applications as described by the awardee: Development of these ternary APC conductors has greater potential for higher J_c at optimal compositions than ternary approaches using melted alloy. Ternary conductors which can incorporate the potentially higher H_{c2} into greater high field (>8 T) J_c than comparable binary alloys will find immediate

use in high energy physics applications. This effort builds upon ternary APC experience to establish the best raw material configuration as well as the thermal and mechanical processes for APC NbTiTa superconductors.

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Niobium-Titanide Tin/Copper Multifilamentary Superconducting Wire with Niobium/Titanium Composite Filaments--Supercon, Inc., 830 Boston Turnpike, Shrewsbury, MA 01545; (508) 842-0174
Dr. Dingan Yu, Principal Investigator
Ms. Elaine Drew, Business Official
DOE Grant No. DE-FG02-94ER81873
Amount: \$74,995

The accelerator, fusion, and nuclear magnetic resonance (NMR) projects in the field of applied superconductivity all require new high-field superconducting wires that have higher current-carrying capability in higher magnetic fields. Up to now, niobium tin (Nb_3Sn) is the most important practical superconductor for high-field applications. One of the effective approaches to raise the critical current densities of Nb_3Sn in high magnetic fields is to alloy Nb_3Sn with titanium (Ti) or tantalum (Ta). The current practice of adding Ti into Nb_3Sn is to use NbTi alloy rods and/or copper (Cu) bronze matrix alloyed with Ti to assemble the monocoil billets. Nevertheless, the processing of these conductors often suffers from drawability problems due to enhanced work hardening. Phase I will investigate the feasibility of developing a ternary ($\text{Nb,Ti})_3\text{Sn/Cu}$ multifilamentary superconducting wire with Nb/Ti composite filaments prepared from pure Nb and Ti sheets using a jelly-roll technique. It has been demonstrated that long lengths of NbTi superconductor with artificial pinning centers (APC) can be fabricated from pure Nb and Ti sheets without precipitation heat treatments. It is expected that use of Nb/Ti composite filaments via a jelly roll technique will improve the fabricability of the ($\text{Nb,Ti})_3\text{Sn/Cu}$ superconducting wire and cut the cost. The fine grain structure in Nb and Ti sheets will also help to enhance the critical current (J_c) in low and intermediate magnetic fields, and reduce the filament sausaging at the same time. In Phase I, two ternary ($\text{Nb,Ti})_3\text{Sn/Cu}$ superconducting wires, one containing Nb/Ti composite filaments and the other containing conventional Nb/1-2wt.%Ti alloy

filaments, will be fabricated using a conventional bronze-route process. The drawability, J_c , magnetization (hysteresis loss), and microstructure of these two wires will be measured and compared. The further optimization and scale-up work will be conducted in Phase II.

Anticipated Results/Potential Commercial Applications as described by the awardee: This project will result in a ternary ($\text{Nb,Ti})_3\text{Sn/Cu}$ superconducting wire with Nb/Ti composite filaments. This superconducting wire with an enhanced high-field J_c , better drawability, and reduced fabrication cost will be an ideal candidate to be used in the superconducting magnets for accelerator, fusion, and NMR projects.

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Object Oriented Programming for Accelerator Design and Analysis--Tech-X Corporation, 6175 Habitat Drive, #3076, Boulder, CO 80301; (303) 530-9562
Dr. Svetlana G. Shasharina, Principal Investigator
Dr. John R. Cary, Business Official
DOE Grant No. DE-FG05-94ER81884
Amount: \$74,739

This project will investigate and document the use of object oriented programming for analysis and design of accelerators by porting existing codes to C++ and using and enhancing an existing class of accelerator elements in a design code. Specifically, the code maps will be ported to a C++ compiler and the beamline class to the C++ compiler of IBM workstations. Coding for accelerator elements in xmaps will be replaced with beamline classes. These replacements will be tested and verified for accuracy at each stage. Finally, documentation of the accelerator classes and their usage will be provided.

Anticipated Results/Potential Commercial Applications as described by the awardee: Result will be a tested set of accelerator element classes that should be available to national laboratories and the public for accelerator design and analysis. These classes will be documented for ease of use.

A Porous Metal Cooled Klystron Collector--
Thermacore, Inc., 780 Eden Road, Lancaster, PA
17601; (717) 569-6551

Mr. John H. Rosenfeld, Principal Investigator

Mr. Richard W. Longsdorff, Business Official

DOE Grant No. DE-FG05-94ER81889

Amount: \$74,985

The objective of this program is to demonstrate the capability of porous metal cooling to effectively remove heat absorbed by a multi-stage depressed collector of high power B-factory klystrons. Heat to be removed can typically be many kilowatts, and peak heat fluxes can exceed 1000 W/cm². Existing channel cooling designs are generally limited to heat

fluxes of less than 1000 W/cm². Porous metal cooling will increase the power capability and design margin for the klystron collector. Tasks to be completed in Phase I include defining detailed requirements for the collector, completing a conceptual design of a porous metal cooled heat exchanger for the target application, and demonstration of a subscale test article to remove an absorbed heat flux goal of 1000 W/cm² to 2000 W/cm² using porous metal cooling.

Anticipated Results/Potential Commercial Applications as described by the awardee: Reliable operation of klystrons with collector heat fluxes of over 1000 W/cm² could be possible for the first time. Applications may also exist for cooling of solid-state electronics, fusion energy components, and aerospace components.

HIGH ENERGY PHYSICS DATA PROCESSING AND DETECTOR INSTRUMENTATION

Ultraviolet-Sensitive Large-Area Avalanche Photodiodes for Improved Calorimetry--

Advanced Photonix, Inc., 1240 Avenida Acaso,
Camarillo, CA 93012; (805) 987-0146

Mr. John Montroy, Principal Investigator

Mr. S. C. Han, Business Official

DOE Grant No. DE-FG03-94ER81697

Amount: \$74,895

This project will extend the responsivity of currently available large-area avalanche photodiodes (APDs) into the blue and near-UV region. APDs can offer significant cost savings and superior performance (high quantum efficiency, compactness, ruggedness, freedom from afterpulsing, magnetic field immunity, and fast time response) over photomultipliers. During Phase I, two parallel approaches will be explored to enhance APDs' blue and near-UV responsivity using boron implantation and wavelength-shifting phosphor coating. The goal is to achieve a 40% quantum efficiency in the wavelength region 200-450 nm. A successful completion of Phase I will demonstrate the feasibility of the technical approach. Phase II would optimize these processes

and develop prototype APDs and APD arrays that are sensitive in the blue and near-UV region.

Anticipated Results/Potential Commercial Applications as described by the awardee: Large-area APDs with enhanced blue and near-UV responsivity will have applications for readout of Aerogel Cerenkov counters and blue scintillating fibers, as well as time-of-flight detectors at the Fermi Lab. Other commercial applications include chemical analysis instruments such as mass spectrometers and activation analysis systems.

The Peripheral Component Interconnection/ Scalable Coherent Interface Bridge for Data Acquisition and Computation Applications--

Bi Ra Systems, Inc., 2404 Comanche Road, NE, Albuquerque, NM 87107; (505) 881-8887

Mr. Lavon R. Biswell, Principal Investigator

Mr. Lavon R. Biswell, Business Official

DOE Grant No. DE-FG05-94ER81716

Amount: \$75,000

Coalescing the fragmented information associated with each event of a high-energy physics detector and then processing it at the rates demanded by accelerator systems are among the largest challenges in the physics community. New detector systems continue to increase the number of measured parameters and simultaneously increase the resolution of detector components so that the volume of generated information is exploding. Data acquisition and computation systems now face staggering amounts of data to both move and process. A peripheral component interconnection (PCI)/scalable coherent interface (SCI) bridge (PSB) that solves both of these data acquisition and computation issues will be developed. This bridge links the high performance PCI, the emerging standard for the internal bus of desktop computers, to the recently developed SCI IEEE standard 1596-

1992. Scalable farms (groups) of inexpensive PCI-equipped desktop computers will connect to large detector systems through the PSB and the highly configurable SCI network to satisfy data rates and to process events from thousands of distributed subsystems. The Phase I research will develop a specification for the PCI/SCI bridge following the form of the proposed 1596.1 SCI VME bridge standard. This work will ensure compliance with both the PCI Local Bus Specification Revision 2.0 and IEEE Standard 1596-1992. A preliminary design minimizing cost through use of commercial components will be developed, PCI/SCI transactions simulated, and bridge latency and throughput performance estimated.

Anticipated Results/Potential Commercial Applications as described by the awardee: It is anticipated that the high performance and versatile architecture of the PCI/SCI bridge will make it an essential building block in the data acquisition and computation systems for high-energy physics experiments now in the planning stages for upgrades or for new construction in the United States and elsewhere. Because of its low latency and high bandwidth, this bridge will be a component of low cost supercomputing clusters in a broad scientific and business market. Such cluster computing accelerates execution of software programs except those that make significant use of vector processing.

NUCLEAR PHYSICS INSTRUMENTATION AND TECHNIQUES

A High Power, Thick Target Design for Irradiation by High Intensity Charged Particle Beams--Amparo Corporation, P.O. Box 2687, Santa Fe, NM 87504; (505) 982-6742

Dr. Willard L. Talbert, Principal Investigator

Dr. James J. Walker, Business Official

DOE Grant No. DE-FG05-94ER81704

Amount: \$74,377

Phase I addresses a new approach for the design of high power nuclear targets used for production of radioisotopes by high energy charged particle beams, notably high energy protons. Such targets will yield

larger quantities of radioactive species than presently available, either for basic research (e.g., studies using radioactive beams) or for applied purposes (e.g., production of medical radioisotopes). There is a need, especially for the production of short-lived radioisotopes, to develop nuclear targets that optimize production of isotopes in the vapor state. This allows on line collection and processing, thus greatly improving the net production efficiency for a given high energy particle beam. This improvement will be achieved by the ability to set the target operating temperature to optimize the diffusion and desorption of the radioisotope species of interest. To this effect, the feasibility of a new target design, utilizing thermal impedance materials such

as porous metals and woven wire meshes interposed between the target chamber proper and the cooling jacket will be studied. Such an approach has attractive features for controlling the transport of heat, and has been proposed in initial concepts for a radioactive beam facility at TRIUMF (Vancouver, B.C., Canada). Successful completion of Phase I will lead to the production of a target prototype to be tested at an existing accelerator facility.

Anticipated Results/Potential Commercial Applications as described by the awardee: The anticipated results of this project are to provide a design basis for target development, to be used in follow-on tests at a high current accelerator, and to provide design options that allow target designs to be developed for a wide range of target operating temperatures. Potential commercial applications include the production of short-lived medical radioisotopes and the potential for on line conventional medical isotope production and separation.

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Jet Vapor Deposition of Thick Films for the Production of Radioactive Beams of Chemically Active Elements--Jet Process Corporation, 25 Science Park, New Haven, CT 06511; (203) 786-5130
Dr. Bret L. Halpern, Principal Investigator
Mr. Jerome J. Schmitt, Business Official
DOE Grant No. DE-FG05-94ER81793
Amount: \$75,000

Radioactive nuclear beams (RNBs) are powerful tools for research in nuclear physics and astrophysics, and for applications in medicine and materials science. In the United States a large laboratory for intense RNBs is contemplated, and smaller facilities exist in several countries; worldwide interest in RNBs reflects their potential importance. RNBs are generated when high energy proton beams interact with specialized, expensive, isotopically enriched targets and release short-lived radioactive species. A critical requirement is that products escape the target promptly lest radioactive decay diminish beam intensity. Target design is complicated by the demands of high yield, efficient use of isotopic materials, chemically reactive products, and prompt release. Targets for production of radioactive ^{14}O and $^{17,18}\text{F}$ are considered of highest priority, but have

not been made. Phase I will solve this problem by using a proprietary jet vapor deposition (JVD) method to deposit multilayer and porous nanocluster thin film RNB targets. Success in Phase I will provide a unique JVD approach to RNB target fabrication and two new types of RNB target. Phases II and III will lead to JVD scale up for commercialization of RNB targets and nanostructure spinoff products.

Anticipated Results/Potential Commercial Applications as described by the awardee: Success in Phase I would prove a new method for making RNB targets of reactive elements. These are expensive, hard to fabricate components critically needed at future RNB facilities both for fundamental research and for applications in materials science and medicine. The JVD techniques developed will also lead to spinoffs in nanostructured thin film products.

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Radiation Detectors Based on Room Temperature Silicon Drift Chamber Arrays--Moxtek, Inc., 452 West 1260 North, Orem, UT 84057; (801) 225-0930
Dr. Mark W. Lund, Principal Investigator
Mr. Lester Y. Moody, Business Official
DOE Grant No. DE-FG05-94ER81817
Amount: \$75,000

Several detector technologies have been developed recently in American and European government and university research laboratories. These technologies combined with planned innovations could be used to create a new type of silicon x-ray detector-spectrometer that has resolution and sensitivity close to present lithium drifted silicon (Si(Li)) detectors, but operates at room temperature. The technologies include silicon drift chambers and Junction Field Effect Transistors (FET) on high resistivity silicon. Combining these innovations on high resistivity epitaxial silicon could produce a room temperature detector which will be competitive with currently available energy dispersive x-ray detectors without the high cost and maintenance associated with liquid nitrogen cooled Si(Li) detectors. They could also have much more collection area than a PIN photodiode of the same resolution. Phase I will develop the low capacitance FET and reset mechanisms necessary for high resolution drift chambers, and

design the semiconductor process and the first draft of the drift chamber layout.

Anticipated Results/Potential Commercial Applications as described by the awardee: Chemical elemental analysis by x-ray fluorescence is a well established technique, but one which requires laboratory based cryogenic equipment. The planned product would open up many more applications for this technique, including mobile, hand held, airborne, and space borne applications. This is a technology that should be useful in current applications which use Si(Li) detectors, and also could open up more applications in space and on earth for these spectrometers. Applications would include prospecting, environmental contamination surveys, scrap metal sorting, process control, and nuclear proliferation monitoring. It is estimated that the market for room temperature detector-based energy dispersive is larger than that for cryogenic detectors.

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A Feasibility Study of a P-Type Silicon Drift Detector for High Precision Radiation Measurements--NOVA R & D, Inc., 1525 Third Street, Suite A201, Riverside, CA 92507-3429; (909) 781-7332
Dr. Charles J. Naudet, Principal Investigator
Ms. Sezen H. Tumer, Business Official
DOE Grant No. DE-FG03-94ER81820
Amount: \$75,000

Nuclear physics experiments need high energy resolution position sensitive particle detectors. The planned experiments at the Relativistic Heavy Ion Collider also require tracking charged particles in a very high multiplicity environment. New state-of-the-art position sensitive detectors are needed. This Phase I project will study the feasibility of a high precision, low cost, position sensitive charged particle tracker, a p-type silicon drift detector (SDD). Prototype versions of n-type silicon drift detectors have been successfully implemented in heavy-ion and high energy physics experiments where they have demonstrated high spatial precision and durability. However, because of the difficulty of obtaining quality high resistivity n-type silicon these detectors have not yet been widely used. High resistivity p-type silicon is readily available and also offers advantages. This Phase I project will focus of the development of large area ($>16 \text{ cm}^2$) p-type silicon

drift detectors. Experiments and simulations will be conducted to study the position and energy resolution, radiation resistance, temperature gradient effects, and optimization of the integrated calibration system. Phase II will extend the development of large p-type SDD to include the production and testing of charged particle tracking and x-ray SDDs, and the devices will be developed for the manufacture of commercial detectors for industrial and scientific applications.

Anticipated Results/Potential Commercial Applications as described by the awardee: A low cost, large area, radiation resistant, precise SDD would find a demanding market not only for charged particle tracking in nuclear physics experiments but also in heavy ion, high energy, and plasma physics. It can be also used in x-ray and gamma ray astronomy. The development of similar x-ray SDDs will find potential uses in commercial applications such as x-ray fluorescence, medical and industrial x-ray imaging, Mossbauer spectrometers, nuclear waste monitoring, and commercial x-ray and gamma ray detectors.

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A Wide Tunable Ultraviolet Detector for a Cherenkov Particle Detection System Using Gallium-Nitride/Aluminum-Gallium-Nitride Multiple Quantum Well Structures--Physical Optics Corporation, 2545 West 237th Street, Suite B, Torrance, CA 90505; (310) 320-3088
Dr. Sueh-Wen Siao, Principal Investigator
Ms. Patty Shaw, Business Official
DOE Grant No. DE-FG03-94ER81827
Amount: \$74,994

The weak ultraviolet (UV) light generated by charged particles traversing an appropriate medium in a ring-imaging Cerenkov (RICH) detection system requires a very sensitive detector array to give the spatial location and the velocity vector of the particles. The low sensitivity of commercially available UV detectors requires the implementation of an external image intensifier, which is bulky, expensive, and fragile. It is planned to fabricate a UV avalanche detector array for identifying the charged particles in RICH detectors. The novelty of this UV detector is the avalanche effect via impact ionization of electrons and holes in a gallium

nitride/aluminum gallium nitride multiquantum well (MQW) structure. The MQW is designed to provide high efficiency and high speed operation by controlling the impact ionization rate of electrons and holes separately. The avalanche effect provides an internal gain that increases the sensitivity of the detector by at least five orders of magnitude. This will eliminate the use of the external image intensifier needed for conventional detection systems. This UV detector has high sensitivity and a large bandwidth. In addition, it is efficient, highly reliable and cost effective for the RICH system. In Phase I a prototype device will be fabricated to demonstrate the feasibility of this concept. In Phase II a fully functional detector array will be fabricated using the optimized parameters.

Anticipated Results/Potential Commercial Applications as described by the awardee: The successful development of the UV detector will result in an efficient, rugged, highly sensitive, and low cost device to be used in RICH particle identification systems. Other applications of the device include laser power measurements, calorimeters, medical analytical instrumentation, industrial processing equipment, pollution monitoring instrumentation, spectroradiometers, and densitometers.

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A Novel Solid State Ultraviolet Detector for Scintillation Readout--Radiation Monitoring Devices, Inc., 44 Hunt Street, Watertown, MA 02172; (617) 926-1167

Dr. Chuxin C. Zhou, Principal Investigator
Dr. Gerald Entine, Business Official
DOE Grant No. DE-FG02-94ER81843
Amount: \$75,000

The overall performance and usefulness of scintillator detectors are often limited by the efficiency of light collection by the photosensor used in conjunction with them. Most scintillators that emit in the ultraviolet region (UV) have not been fully exploited, chiefly due to the difficulty of measuring the light output in that range. For example, BaF_2 is an attractive scintillation detector for γ -rays, neutrons and charged particles because of its radiation hardness and fast time response. However, since its fast light component is well into the UV, only Photomultiplier Tubes (PMTs) with

special UV transmitting windows can be used. Even the special PMTs do not achieve good performance with these scintillators, and they are expensive. The plan is to develop a novel solid state photosensor which will have the exceptional performance, in the ultraviolet region of the spectrum, that will take full advantage of the performance of these UV scintillators. This sensor can be fabricated in the form of high resistivity, low dielectric constant films, has excellent radiation hardness and has a tunable bandgap which optimally covers the UV spectrum of interest. This device will be made using the ternary semiconductor Gallium Aluminum Nitride ($\text{Ga}_{1-x}\text{Al}_x\text{N}$). With this new device, it should be possible to make very compact, rugged and extremely high performance scintillator modules which could find wide applications in nuclear instrumentation technology.

Anticipated Results/Potential Commercial Applications as described by the awardee: $\text{Ga}_{1-x}\text{Al}_x\text{N}$ photodetectors would offer a solid state replacement to PMTs for light detection from scintillators that emit in the UV and are used in intermediate and high energy physics experiments. In general, $\text{Ga}_{1-x}\text{Al}_x\text{N}$ detectors would also find applications in detection of UV radiation from flames in combustion control in industrial processes and for surveillance in space applications. Monitoring of UV processes like UV curing and UV photolithography could also benefit from it.

206

Low Cost Avalanche Photodiodes for Scintillation Detection--Radiation Monitoring Devices, Inc., 44 Hunt Street, Watertown, MA 02172; (617) 926-1167

Dr. Gerald Entine, Principal Investigator
Dr. Gerald Entine, Business Official
DOE Grant No. DE-FG02-94ER81842
Amount: \$75,000

Silicon avalanche photodiodes (APDs) have been shown to be nearly an ideal replacement for photomultiplier tubes (PMTs) in scintillation detection applications. However, because of their great expense (typically APDs cost ten times as much as an equivalent PMT) APDs have not been widely used. The high cost of APDs is due to the low yield, labor-intensive manufacturing process used to

produce them. The purpose of this project is to develop a new APD design that can be manufactured entirely using automatic methods employed in the integrated circuit (IC) industry. The goal of the Phase I effort is to demonstrate that it is possible to fabricate APDs with performance comparable to present devices using standard silicon IC processing technologies. During Phase I an appropriate APD structure will be designed and the necessary fabrication steps developed and tested. By the end of Phase I, APDs will be fabricated using this process and tested as detectors. Phase II of this effort will continue the research and examine ways to improve performance and reduce cost to produce a process that is compatible with larger scale, low cost silicon device manufacturing. If successful, the proposed research would result in a low cost solid state alternative to PMTs.

Anticipated Results/Potential Commercial Applications as described by the awardee: These devices would find widespread use as a PMT replacements in nuclear physics research for scintillation detector applications, and should have a large commercial market.

207

Microchannel Plates Fabricated by Track Etch Lithography--Spire Corporation, One Patriots Park, Bedford, MA 01730-2396; (617) 275-6000
Dr. Charles C. Blatchley, Principal Investigator
Mr. Patrick N. McDonnell, Business Official
DOE Grant No. DE-FG02-94ER81868
Amount: \$74,981

Tiny channels can be formed in polymers and glass by chemical etching along columns of radiation damage created by alpha particle bombardment through microscopic holes in a dense mask. The objective of Phase I research is to determine whether a dense packing of these channels, carried through the irradiated substrate, can reliably form micro channel plates (MCP) suitable for amplifiers for imagers and other optoelectronic devices. The reduction in channel diameters compared to those characteristics of drawn glass-fibers will preserve gain and efficiency while improving spatial resolution and response time. Most significantly, this will greatly reduce costs through a simple two-step process similar to photolithography where holes in a

mask are positioned to optimize channel locations. Phase II would use this deep ion-damage etching process to make large plates with identical channel locations, providing high registration efficiency over large areas and further improving the resolution of finished devices.

Anticipated Results/Potential Commercial Applications as described by the awardee: Microchannel plates are used in imaging, ranging, and night vision instruments. Many medical imaging systems, mass spectrometers, scintillation detectors, and optical communication links rely on this technology, and would benefit from the expected improvements in resolution, response, and fabrication cost.

208

Low Cost Substrates for Micro-Strip Gas Chambers--Surmet Corporation, 33 B Street, Burlington, MA 01803; (617) 272-3250
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DOE Grant No. DE-FG02-94ER81876
Amount: \$75,000

Micro-Strip Gas Chambers (MSGC) are high resolution counting devices for detecting events produced by particle-particle and heavy ion collisions in high energy accelerators. They are of great interest because of their fine granularity, high gain and potential for low cost, large area event detection. MSGCs have been demonstrated by several research and industrial concerns and the early results suggest that large area (250 mm x 180 mm) devices can be manufactured that will suit the research needs. Manufacturing of MSGCs follow the methods of the microelectronics industry, with thin film technology and microlithography playing key roles in depositing patterned metal films on insulating substrates. Current estimates for the large scale manufacturing of a single MSGC are about \$700 for a 100 mm² device, not including the cost of the substrate. Unfortunately, the current estimates for substrate cost are about equal to the device manufacturing cost. Clearly, the development of a low cost substrate is crucial to making this device economically feasible. A low cost multilayered thin film structure is planned to achieve the required properties and to provide a surface with a sheet

resistance that is controllable in the 10^{12} to 10^{14} ohms/square range. A low cost flexible engineering polymer will be used as a substrate onto which the multilayered thin film structure will be deposited. Excellent adherence to the metal electrodes to the proposed surface is also expected. Cost for a MSGC substrate using this technique is estimated to be less than 1/10 of the current estimated substrate cost.

Anticipated Results/Potential Commercial Applications as described by the awardee: Micro-Strip Gas Chambers are seen as a critical component of future particle event detection devices for high energy physics research. The development of a low cost substrate for MSGCs should make them economically feasible. The technology to be developed through this program could have application to both the microelectronics field and the expanding fields of large area coating of polymers for electronics, biomaterials and tribological applications.

209

Radiation-Hard and Solar Blind Ultraviolet X-Ray Chemically Vapor Deposited-Diamond Photodiode Detectors--Vacronic Laboratory Equipment, Inc., 160 Wilbur Place, Bohemia, NY 11716; (516) 567-0520

Mr. Glenn Fricano, Principal Investigator

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DOE Grant No. DE-FG02-94ER81896

Amount: \$73,902

This project deals with the development of radiation-hard and solar blind photodetectors made from chemical-vapor-deposited (CVD) diamond, tailored to have responsivities between 5 eV and 5 keV, i.e., from ultraviolet (UV) wave lengths down to the X-ray region. Being a wide bandgap semiconducting material, its electrical properties include, among others, (a) solar blindness, meaning that it is not sensitive to visible light, and (b) very low leakage (or dark) current, even under high voltage bias and at elevated temperatures. The first property allows convenient applications under normal daylight and room illuminations. The latter results in low noise figures significantly better than those of silicon photodetectors presently in common use. Two different structures or prototypes of photodiodes will be optimized in Phase I. The first is a conventional

metal-semiconductor-metal structure, in which a CVD diamond layer is sandwiched between two metal layers or electrodes. The second type of photodiode is furnished with alternating lines of metal electrodes arranged side-by-side, facing the incoming radiation, such that shallow light penetrations do not impede its performance. By virtue of proper design, this type of photodiode is expected to be capable of very high frequency operations in the 100 GHz range, although the Phase I goal is only 4 GHz. For both prototypes, one-inch diameter intrinsic diamond films on molybdenum substrates will be grown using a microwave plasma reactor and metalized using carbide-forming metals such as titanium and molybdenum along with gold in an electron-beam evaporator.

Anticipated Results/Potential Commercial Applications as described by the awardee: Potential applications of these new photodiodes are (a) as robust, room-temperature, solar blind, position-sensitive UV and X-ray (array) detectors for use in medicine, space astronomy, high altitude atmospheric research, non-destructive material testing (NDMT), nuclear and high energy physics, fusion research, and safeguards/security inspections; (b) as X-ray fluorescence detectors in nuclear waste management, environmental restoration, NDMT, and nuclear non-proliferation; (c) as radiometric transfer standard detectors for use by the private industry, government, and military; and (d) as high-speed receivers for fiberoptic communications.

210

Dynode Material Studies for a Novel Two Dimensional Electron Multiplier--X-Ray Instrumentation Associates, 2513 Charleston Road, Suite 207, Mountain View, CA 94043-1607; (415) 903-9980

Dr. Yuan Kong, Principal Investigator

Dr. William K. Warburton, Business Official

DOE Grant No. DE-FG03-94ER81902

Amount: \$75,000

The photomultiplier tube (PMT), consisting of a photocathode and a dynode based electron multiplier (EM), is an important electro-optic device in a variety of radiation measurements. It is a versatile and sensitive detector with low noise and fast response time. The EM dynode structures, however, preclude

fine grain, two-dimensional (2-D) position sensitivity using conventional designs. Mesh dynodes have been developed to address this issue but, due to lateral spreading of the electron avalanche between stages, are still typically limited to 1-2 mm in position resolution. This project proposes a novel EM design that should achieve resolutions of 100 μm or less while preserving the benefits of the classical dynode structure. Other benefits include: count rates up to $10^7/\text{sec}$ per $(100\mu\text{m})^2$ pixel, improved timing resolution, essential gain independence of axial magnetic field, and the possibility of active areas up to 20 cm in diameter. Phase I will focus on dynode material identification and selection, which is the key element in the new geometry. Success in this project

will provide the necessary basis for developing a 2-D electron multiplying structure that would have a wide range of instrumentation applications.

Anticipated Results/Potential Commercial Applications as described by the awardee: Success in this project will lead to the development of a 2-D imaging electron multiplier structure that will possess several improved characteristics over presently available devices. Count rate capability, 2-D spatial resolution, timing resolution, and magnetic field immunity are all expected to improve greatly. Such a device would enhance performance in applications ranging from nuclear physics to medical and biological imaging, and would open new horizons in a variety of fields.

NUCLEAR PHYSICS ACCELERATOR TECHNOLOGY

211

A High Power Solid-State Amplifier--Amparo Corporation, P.O. Box 2687, Santa Fe, NM 87504; (505) 982-6742

Dr. Don W. Reid, Principal Investigator
Dr. James J. Walker, Business Official
DOE Grant No. DE-FG05-94ER81703
Amount: \$74,607

During the past 10 years significant progress has been made in the performance characteristics of solid-state devices. The output power capability has substantially increased, the efficiency has almost doubled, the reliability, when operated conservatively, has always been better than tubes because of graceful degradation characteristic, and the cost per device has decreased. These and other positive solid-state amplifier characteristics will be applied to the design of a state-of-the-art 5 Kw, 1500 Mhz, 40% efficient, 45 dB amplifier that could replace the present Continuous Electron Beam Accelerator Facility (CEBAF) klystron tube. The use of an integral dc to dc converter will be investigated. The converter would be part of the amplifier package and would enable the amplifier to run directly from the 11.6 kV dc voltage bus that presently exists. The end result would be an amplifier with better efficiency, more gain, better reliability, easier

maintenance and lower system operating cost than the existing tube. In addition, the amplifier could replace the existing tube with only minor system modifications.

Anticipated Results/Potential Commercial Applications as described by the awardee: The successful development of this amplifier should be directly beneficial to CEBAF where it can potentially replace 338 klystrons. There could also be a large potential commercial application in the new personal communication services band from 1.85 to 2.2 GHz.

212

A Framework for a General Purpose Intelligent Control System for Particle Accelerators--Vista Control Systems, Inc., 134-B Eastgate Drive, Los Alamos, NM 87544; (505) 662-2484

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DOE Grant No. DE-FG05-94ER81897
Amount: \$73,803

The tuning and control of particle accelerators is a time consuming and expensive task. The control problem, in general, is inherently non-linear and one

to which conventional control methods cannot be satisfactorily applied. Advanced information technologies such as expert systems and neural networks have been applied separately to these problems with limited success. Few, if any, of these advanced information technologies have been applied for general use or in a manner usable by multiple accelerator installations. In Phase I existing neural network and expert system technologies will be coupled to provide a general purpose, intelligent control system. This approach offers a feasible solution to the complex control problems encountered in accelerator controls. These technologies will be integrated within the framework of an existing commercial, general purpose control system that is extensively used by the accelerator control community. Also, typical and realistic scenarios in accelerator control will be defined using a commer-

cial accelerator modeling code that will be enhanced to incorporate realistic noise effects. These scenarios will be used as a test platform for the general purpose control framework being developed as part of this work.

Anticipated Results/Potential Commercial Applications as described by the awardee: A framework for intelligent control and monitoring of complex accelerator control scenarios that can be packaged and marketed as an advanced information tool as part of an existing accelerator control product is expected. The definition and implementation of realistic and typical control scenarios that can be used by other researchers for benchmarks to facilitate communications and research in this problem area will result from this work.

APPENDIX A

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APPENDIX C

Proposal Submissions and Awards Listed by States, Territories, and Possessions

<u>State</u>	<u>Number Submitted</u>	<u>Number Selected</u>	<u>State</u>	<u>Number Submitted</u>	<u>Number Selected</u>
Alabama	26	1	Montana	14	0
Alaska	2	0	Nebraska	2	0
Arizona	38	4	Nevada	6	0
Arkansas	15	0	New Hampshire	13	0
California	439	51	New Jersey	72	7
Colorado	111	16	New Mexico	67	8
Connecticut	91	15	New York	101	6
Delaware	16	4	North Carolina	28	3
District of Columbia	1	0	North Dakota	7	1
Florida	56	1	Ohio	72	2
Georgia	13	0	Oklahoma	24	0
Hawaii	4	0	Oregon	29	7
Idaho	13	0	Pennsylvania	61	6
Illinois	62	3	Puerto Rico	1	0
Indiana	3	1	Rhode Island	4	0
Iowa	14	1	South Carolina	4	0
Kansas	4	0	South Dakota	2	0
Kentucky	6	0	Tennessee	47	4
Louisiana	43	1	Texas	113	5
Maine	12	1	Utah	44	4
Maryland	80	2	Vermont	10	2
Massachusetts	251	37	Virginia	97	7
Michigan	46	4	Washington	55	5
Minnesota	19	2	West Virginia	2	0
Mississippi	1	0	Wisconsin	16	1
Missouri	14	0	Wyoming	5	0

Although eligible in each case to participate, there were no submissions from the Virgin Islands, the Commonwealth of the Northern Mariana Islands, or the Trust Territory of the Pacific Islands.

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