Small Business Innovation Research

Abstracts of Phase I Awards 1987

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SBIR Program Manager
Office of Energy Research
U.S. Department of Energy
Washington, D.C. 20545

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Small Business Innovation Research

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Abstracts of Phase I Awards 1987

SBIR Program Manager
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PREFACE

Contained in this booklet are abstracts of the Phase I awards made in Fiscal Year 1987 under the Small Business Innovation Research (SBIR) program in the Department of Energy (DOE). This program, now completing its fifth year, was established in compliance with the Small Business Innovation Development Act, Public Law 97-219.

As prescribed in the legislation, the program is designed for implementation in a three-phase process, 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 relatively brief, typically about 6 months, and the awards are limited to \$50,000. Phase II is the principal research or research and development effort, and the awards are as high as \$500,000 for work to be performed in periods of up to 2 years. Phase III is the commercial application of the research or research and development effort by small businesses with non-Federal capital or, alternatively, it may involve follow-on non-SBIR Federal contracts for products or services desired by the Government.

The 111 Phase I projects described here were selected in a highly competitive process from a total of 942 proposals received in response to the 1987 Solicitation. Prior DOE releases naming the firms selected for awards may have discrepancies due to firms not proceeding to contracts. The selections for awards were made on scientific and technical merit, as judged against the specific evaluation 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.

The work described in the abstracts represents high-risk research, but the benefits are also 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 respective firm directly.

Samuel J. Barish
SBIR Program Manager
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Washington, DC 20545

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CHEMICAL SCIENCES RESEARCH

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Interfacial Condensation Polymers for Analyte-Specific Sensor Coatings—Bend Research, Inc., 64550 Research Road, Bend, OR 97701-8599; 503-382-4100

Dr. James R. Lowell, Jr., Principal Investigator
Dr. Walter C. Babcock, Business Official
DOE Contract No. DE-AC03-87ER80514
Amount: \$49,367

Many U.S. industries are finding that their survival will depend on substantially improved productivity. The development of new sensors is vital to the implementation of robotics or automation, the most common means of increasing productivity. In one of the most practical approaches to analyzing complex mixtures, partially selective sensors are combined in an array with appropriate electronic processing of the various responses. A new approach to the preparation of partially selective sensors will be investigated, in which an analyte-selective polymer film is applied to a piezoelectric polyvinylidene fluoride (PVDF) film. The analyte-selective polymers chosen should be capable of producing a physical response that can be converted to an electrical signal by the piezoelectric film. Sensors based on piezoelectric materials have been used primarily to measure vapor-phase components. The sensors resulting from this program, however, will be intended specifically for measuring concentrations of components of liquid solutions. Such sensors would have wide application for automated process control in the chemical industry.

Anticipated Results/Potential Commercial Applications as described by the awardee: In the Phase I program, one or more sensors based on application of analyte-specific polymers to piezoelectric films will be developed and tested for sensitivity to three representative analytes. If the results are favorable, the next logical stage will be continuation into a Phase II program to evaluate a wider range of polymers for a greater number of analytes and determine the sensitivities of various combinations and configurations. Further testing will be undertaken on actual chemical process streams. Once commercialized during Phase III, these sensors could be used

in process monitoring and control in a wide range of chemical manufacturing plants.

2

Novel High-Flux Antifouling Membrane Coatings—Bend Research, Inc., 64550 Research Road, Bend, OR 97701-8599; 503-382-4100

Dr. Paul van Eikeren, Principal Investigator
Dr. Walter C. Babcock, Business Official
DOE Contract No. DE-AC03-87ER80466
Amount: \$49,821

Membrane fouling, the long-term irreversible decline in permeate flux, greatly limits the application of energy-efficient membranes to industrial processing needs. The economics of many current membrane processes would be improved and the introduction of new membrane applications would be accelerated if existing membranes could be modified to exhibit (1) higher permeate fluxes without attendant loss of selectivity, (2) higher resistance to fouling, and (3) improved response to cleaning procedures. In this fundamental research program, a novel materials concept will be pursued to modify the surface characteristics of existing membranes. This approach places an ultrathin coat of a naturally occurring, highly hydrophilic polymer on the surface of existing membranes. The coated membrane promises to exhibit improved water flux, improved resistance to fouling by proteinaceous and oily materials, and improved response to cleaning procedures. The concept is applicable to a wide range of membranes, including those used for microfiltration, nanofiltration, dialysis, electro dialysis, ultrafiltration, and reverse osmosis.

Anticipated Results/Potential Commercial Applications as described by the awardee: In Phase I, a process will be developed for coating ultrafiltration membranes. The coated membrane is expected to display higher water flux and improved resistance to fouling by proteins and oily substances when compared with the uncoated membrane. The coated membranes will allow the processing of streams containing highly fouling materials, including various oilfield waste waters, food-processing waste streams, and industrial waste streams contaminated with organics.

High-Flux, High-Selectivity Cyclodextrin Membranes—Bend Research, Inc., 64550 Research Road, Bend, OR 97701-8599; 503-382-4100

Dr. Paul van Eikeren, Principal Investigator

Dr. Walter C. Babcock, Business Official

DOE Contract No. DE-AC03-87ER80467

Amount: \$49,821

In developing membranes to perform separations, two major technical issues must be addressed: permeate flux and membrane selectivity. A major barrier to the application of membranes in gas or liquid separations is the lack of membrane materials that exhibit both high flux and high selectivity. The application of membranes to industrial-scale separations would be accelerated significantly by the development of new membrane materials and concepts that lead to improvements in both of these areas. In this program a novel, ultrathin molecular-sieve membrane will be developed that consists of an array of ordered channels. The channels will have three important characteristics: (1) channel diameters will be of molecular dimensions, (2) all channels will have the same diameter, and (3) the channels will traverse the membrane. The planned molecular-sieve membrane is expected to exhibit high permeate flux (due to its extreme thinness), high channel density, and a high degree of channel orientation. Additionally, the molecular-sieve membrane is expected to exhibit high selectivity among closely related molecular structures (e.g., structural and geometric isomers) because of the channel characteristics listed above.

Anticipated Results/Potential Commercial Applications as described by the awardee: The planned molecular-sieve membrane will have several advantages over conventional membranes. The principal advantages are high flux and high selectivity for many important separations, such as the removal of phenol from waste water, the recovery of amino acids from fermentation beer, and the separation of isomeric mixtures of benzene derivatives (e.g., xylene). Successful development of the channel-containing membrane also will provide the basis for fabricating ordered membranes from other materials displaying high flux and high selectivity.

Photovoltaic and Photoelectrochemical Properties of Polydiacetylenes—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 Contract No. DE-AC01-87ER80435
Amount: \$50,000

Semiconductor polymers hold promise as very inexpensive photoconversion materials with high electronic mobilities compared with molecular organic crystals. Unfortunately, these materials, exemplified by polyacetylene, can be made only in a highly disordered, porous morphology, so that charge transport is dictated by extrinsic features. Polydiacetylenes (PDAC) are exceptional, however, because they can be made as single crystals by solid state polymerization of the parent monomer. Recent reports of chemical doping of PDAC crystals indicate that they can be made sufficiently conductive to evaluate as photovoltaic materials. It is planned in Phase I to prepare single crystals of a representative PDAC with a range of doping levels (p-type). Solid state diodes of configuration Au/p-PDAC/Al (transparent) will be fabricated and their dark and photoelectric properties evaluated as a function of wavelength, intensity, doping, and crystalline orientation. Au/p-PDAC electrodes will also be investigated as photoelectrodes in a nonreactive, nonaqueous electrolyte. The results will be interpreted in terms of current theories of light-induced charge generation and separation. The mechanism limiting photovoltaic activity will be used to design chemical modifications to the PDAC structure, which are likely to result in improved performance.

Anticipated Results/Potential Commercial Applications as described by the awardee: Phase I work will demonstrate whether a high mobility, ordered organic semiconductor has promise for solar energy conversion. Commercially, organic-based solar cells could be produced very inexpensively by conventional polymer technology. In addition, the PDAC family has applications as optical materials, as electrical conductors for electromagnetic shielding, and as a photo-printable conductive thin film for electronics.

Modeling and Observation of Wave Modes Important to the Functioning of Piezoelectric Mass Sensors—Integrated Chemical Sensors Corporation, 44 Mechanic Street, Newton, MA 02164; 617-965-6950

Dr. Glenn J. Bastiaans, Principal Investigator

Dr. Carl M. Good, Business Official

DOE Contract No. DE-AC02-87ER80498

Amount: \$49,680

The long-term objective of the planned work is to produce advanced chemical sensors for environmental monitoring, industrial process control, and other potential applications. The objectives of Phase I are to produce an accurate mathematical model of the

physical and electrical behavior of surface acoustic wave (SAW) mass sensors in order to achieve significantly improved designs. It is known that SAW sensors are electronic devices that respond to the deposition of mass on their surface. In this research plan the propagation of acoustic surface waves through thin piezoelectric crystals will be studied to determine how mass response occurs in the presence of a liquid and how such a response can be controlled. Preliminary models will be prepared, and their predictions will be compared with experimental observations of acoustic wave velocities and crystal particle displacements. Modifications to the model and experimental measurements will be made repetitively until the two converge. The model will then be extended to account for the presence of thin films and liquids on the surface of the SAW devices. The same strategy of comparison between model predictions and experiment will be applied to ensure model accuracy. After an extended model is completed, it will be used to predict a best sensor design, which then will be experimentally tested and optimized through a specialized experimental design strategy.

Anticipated Results/Potential Commercial Applications as described by the awardee: SAW sensors for the detection of agents in unprocessed sample matrices have broad benefits and commercial applications in many markets including but not limited to environmental monitoring and industrial process control. Their use in rapid and remote detection of hazardous materials might accrue significant safety benefits and help ensure compliance to prescribed handling procedures. In process control, such sensors could provide such detailed information that the efficiency of chemical and other manufacturing processes would be increased dramatically.

6

Continuous Ion Mobility Monitoring as a Liquid Stream Process Sensor—Precision Analytics, Inc., P.O. Box 162, Palouse, WA 99161; 509-878-1785
Mr. Christopher Shumate, Principal Investigator
Mr. Richard M. Worthington, Business Official
DOE Contract No. DE-AC03-87ER80544
Amount: \$48,820

In a wide variety of industries, many industrial processes use flowing streams of liquids and gases. Because these streams are a complex mixture of chemical compounds, knowledge of the constituents is essential for process control, quality control, and process improvement. Many prevalent monitoring techniques require that a sample be extracted from the stream and analyzed *ex situ* using standard

chemical analytical methods such as gas chromatography, mass spectrometry, etc. The existing techniques that are capable of monitoring the process stream *in situ* are either limited to specific constituents or have poor sensitivity. Consequently, existing continuous-monitoring techniques have limited utility (such as warning for alarm conditions). A novel liquid process stream sensor is planned that makes use of the fact that ions of a compound drift with a unique mobility in an applied electric field. Hence, a spectrometer can be built that detects the various constituents of a liquid process stream using their ion mobility signature. The *in situ* continuous monitoring of the stream is accomplished by directing a small portion of a flowing process stream into the ion mobility spectrometer using a novel sensing head. This sensing head, called the electrospray ionization chamber, needs very small samples (on the order of microliters per minute) for operation. Hence, the process stream itself is undisturbed by the monitoring operation. Because the ion mobility spectrometer is based on a general scientific principle it is capable of monitoring a wide variety of process liquids.

Anticipated Results/Potential Commercial Applications as described by the awardee: This process sensor would provide real-time concentration monitoring in flowing systems, allowing direct feedback to controllers. It would be flexible to monitor any species of interest from among the stream constituents.

7

An Infrared Optoacoustic Spectrometer with Wide Applicability for Measurement of Trace Gas Concentrations—Southwest Sciences, Inc., 1570 Pacheco Street, Suite E-11, Santa Fe, NM 87501; 505-984-1322

Dr. Alan C. Stanton, Principal Investigator
Dr. Alan C. Stanton, Business Official
DOE Contract No. DE-AC03-87ER80543
Amount: \$49,996

Existing instrumentation for chemical analysis of gas mixtures do not provide the capability for real-time measurement of a broad range of species at trace (ppb) concentration levels. Such a capability is important in many applications in atmospheric research, pollution control, toxic gas sensing, and industrial process monitoring. Although specialized laser methods have been demonstrated for measuring selected species, none of the methods developed to date has the desired combination of high sensitivity and wide generality. This study will investigate the optoacoustic detection of gas species using new

higher power tunable diode lasers that are now commercially available. This approach combines the high sensitivity of optoacoustic detection with the generality of tunable infrared diode laser spectroscopy for measurement of many different species. A goal of Phase I is to demonstrate detection sensitivity equivalent to species concentrations well below 1 ppb for most infrared-active molecules. The Phase I study will emphasize an assessment of design factors and measurement approaches to optimize the sensitivity under conditions in which a gas mixture is being continuously sampled. The results of Phase I will provide the required data to permit the Phase II development of prototype instrumentation that can be used for ultrasensitive real-time chemical analysis of gas mixtures in a wide range of research and industrial applications

Anticipated Results/Potential Commercial Applications as described by the awardee: Instrumentation based on the infrared diode laser optoacoustic technique has many potential commercial applications in research and industry. Examples include research instrumentation for atmospheric sciences, combustion studies, and advanced materials processing, as well as industrial instrumentation for pollutant monitoring, toxic gas detection, and process feedback and control.

8

The Development of a Molecular Intracavity Diode-Laser Absorption Spectrometer (MIDAS)—Spectral Sciences, Inc., 111 South Bedford Street, Burlington, MA 01803; 617-273-4770
Dr. Neil Goldstein, Principal Investigator
Dr. Fritz Bien, Business Official
DOE Contract No. DE-AC02-87ER80452
Amount: \$50,000

There is a need for chemical vapor monitors that are very sensitive and selective. Optical techniques are well suited for this problem, because they offer selectivity, sensitivity, rapid response, and can be used in extreme temperature and pressure environments. However, it is difficult to combine these features in a single simple device. Intracavity diode laser absorption offers the promise of combining these features. Intracavity absorption involves placing the sample within a laser cavity, which provides multiple passes through the sample. Very long absorption path

lengths can be attained on the order of hundreds of kilometers for a 10-cm laser cavity. Furthermore, the diode lasers can be tuned to specific wavelengths so that particular molecular species can be monitored. In Phase I, an extended cavity diode laser will be constructed to demonstrate the feasibility of using GaAlAs diodes for intracavity absorption detection. The results obtained from the Phase I measurements will be used to design a breadboard Molecular Intracavity Diode-Laser Absorption Spectrometer (MIDAS) to be built in Phase II.

Anticipated Results/Potential Commercial Applications as described by the awardee: It is expected that the GaAlAs-based MIDAS will serve as a basis for low cost, highly sensitive analytical sensors in the visible and near infrared. These sensors will provide high species specificity, high spatial and temporal resolution, and will be useful under a broad range of experimental conditions.

9

A Fiber Optic, Raman Chemical Sensor—TACAN Corporation, 2111 Palomar Airport Road, Suite 270, Carlsbad, CA 92008; 619-438-1010
Dr. Michael M. Salour, Principal Investigator
Mr. Paul V. Sundquist, Business Official
DOE Contract No. DE-AC03-87ER80533
Amount: \$50,000

The investigation of a fiber-optic chemical sensor that will provide localized chemical analysis by nonintrusive, optical methods is planned. The planned fiber-optic probe will have the additional advantages of providing a real-time response; it can be used in hostile (temperature, pressure, and electromagnetic) environments and features a remote display. Molecular concentrations at the parts-per-million level can be identified, and wavelength dispersion of the optical signal can provide measurements of numerous different species concurrently.

Anticipated Results/Potential Commercial Applications as described by the awardee: The results should eventually lead to an instrument that would have numerous applications. The planned fiber-optic Raman chemical sensor could be used in manufacturing quality control, in semiconductor wafer processing, in petroleum refining, and in chemical synthesis.

MATERIALS SCIENCES

10

Premonochromator X-Ray Optic Substrate Development for New Generation Synchrotron Source Beamlines—Advanced Research and Applications Corporation, 425 Lakeside Drive, Sunnyvale, CA 94086-4701; 408-733-7780

Mr. William Warburton, Principal Investigator

Dr. Robert A. Armistead, Business Official

DOE Contract No. DE-AC03-87ER80534

Amount: \$49,124

The new generation of synchrotron radiation (SR) sources promises to extend significantly the regimes of photon energy and intensity available to materials scientists and other researchers. A key challenge to developing these new SR sources is the construction of premonochromator x-ray beamline optics that survive and function under the intense heat loading produced by these machines. An efficiently cooled, mechanically stabilized substrate assembly is planned, which will complement the use of layered synthetic microstructure x-ray interference mirror as a premonochromator element. The outcome of Phase I will be the design of a feasible substrate assembly that employs heat-pipe technology to effect efficient heat extraction from the optically active surface of the premonochromator.

Anticipated Results/Potential Commercial Applications as described by the awardee: A successful project will provide to the synchrotron radiation research field a method for maintaining the integrity of beamline premonochromator optics at the new generation SR source facilities. This technology also will contribute to optic component construction in the field of high intensity lasers and other high energy-content optical systems.

11

The Preparation of High Temperature Intermetallic Compounds at Low Temperatures—Advanced Technology Materials, Inc., 520-B Danbury Road, New Milford, CT 06776; 203-355-2681

Dr. Ward Stevens, Principal Investigator

Dr. E. G. Banucci, Business Official

DOE Contract No. DE-AC01-87ER80470

Amount: \$49,913

Intermetallic compounds, in particular aluminides, silicides, and beryllides, are known for their high

melting points and corrosion and oxidation resistance. Many of these compounds have low densities and very high strengths and, therefore, are of interest for high temperature applications. However, conventional processing of intermetallic compounds suffers severe limitations, namely reactions with containers, porosity, contamination of powder surfaces, and compositional inhomogeneities. Recent work on low temperature chemical vapor deposition (CVD) of metals from organometallic compounds for electronics applications suggests the possibility of fabricating certain intermetallic compounds by CVD. Because organometallic CVD operates at low temperature, employs highly pure starting materials, deposits material uniformly, and requires comparatively little materials handling, it has the potential to solve the problems described above. In the Phase I study, a low temperature CVD technique will be used to apply coatings and to infiltrate a fiber preform with NiAl. The technology developed for this system will serve as an example for several other intermetallic compounds of interest to the DOE during Phase II. Materials made by these techniques have potential uses as structural alloys in fusion energy systems, erosion resistant alloys for fossil energy systems, and intermetallic coatings for a variety of high temperature heat engine materials.

Anticipated Results/Potential Commercial Applications as described by the awardee: Intermetallic materials produced by low temperature CVD can be applied to a variety of materials to serve as corrosion, wear, or oxidation resistant layers for chemical and/or nuclear reactors, fluidized bed reactors, and high temperature engines.

12

High Thermal Conductivity Sintered AlN—Ceramatec, Inc., 2425 South 900 West, Salt Lake City, UT 84119; 801-972-2455

Dr. Raymond A. Cutler, Principal Investigator

Mr. John F. Grennan, Business Official

DOE Contract No. DE-AC05-87ER80503

Amount: \$49,950

Aluminum nitride (AlN) is an important candidate material for advanced packaging of integrated circuits as a high thermal conductivity alternative to beryllium oxide that could potentially be made available at low cost. Much experimental work has been conducted on AlN, but the technology still has

not reached a level suitable for application. Advances are needed especially in sintering technology and in tailoring the microstructure/phase composition to optimize thermal conductivity, dielectric properties, and ease of metallization. A combination of thermodynamics and experimentation will be used to achieve an improved fundamental understanding of the interrelationships between of the densification, composition, microstructure, and properties. Specifically, preliminary analysis and previous experience working with the University of Utah indicate that oxide additions can be developed for AlN that provide a liquid phase during sintering and at the same time act as a getter to remove oxygen dissolved in the AlN—thus increasing thermal conductivity.

Anticipated Results/Potential Commercial Applications as described by the awardee: The Phase I and Phase II efforts should provide the technology base for fabrication of AlN of high thermal conductivity by pressureless sintering. This is a highly sought technology for advanced electronics packaging. It also has potential for heat engines, wear parts, and high temperature fixtures.

13

New Low Thermal Expansion Structural Ceramics—
Ceramtec, Inc., 2425 South 900 West, Salt Lake City, UT 84119; 801-972-2455
Mr. Santosh Y. Limaye, Principal Investigator
Mr. John F. Grennan, Business Official
DOE Contract No. DE-AC05-87ER80502
Amount: \$49,994

Over the past few years, a new family of materials called NZP ($\text{NaZr}_2(\text{PO}_4)_3$ and its analogs) has become well known for its low thermal expansion behavior. Recently, it has been shown that $\text{Zr}_4(\text{PO}_4)_6$ and $\text{SrZr}_4(\text{PO}_4)_6$ have opposite anisotropy in thermal expansion as well as opposite bulk thermal expansion and that their solid solution results in lower anisotropy and near zero thermal expansion. These materials and their analogs have great potential for use in high temperature applications. The reduced anisotropy reflects the advantage over some materials, such as aluminum titanate, cordierite, and others, that are currently used in high temperature applications. Therefore, it is possible to develop new materials with high thermal shock resistance and controlled thermal expansion. The major advantages of these materials are their flexibility towards ionic substitution, their tailorability of the bulk and axial thermal expansion, and their ability to operate safely and reliably over a wide range of severe thermal shock and temperature cycling. In addition, these

materials are easy to synthesize in their single phase forms using inorganic sol-gel synthesis techniques. The Phase I efforts should demonstrate the feasibility of the concept of fabricating dense ceramic bodies of various different compositions having low thermal expansion, high thermal shock resistance, and adequate mechanical strength.

Anticipated Results/Potential Commercial Applications as described by the awardee: Phase I research should result in fundamental understanding of the effects of ionic substitutions on different thermal and mechanical properties of NZP materials. Improved thermal shock resistance and thermal expansion will be achieved by crystal chemical substitution of NZP materials. These materials will have applications in ceramic heat engines, other high temperature situations, and in automobile catalytic converters.

14

High Density Silicon Nitride Ceramic Materials—
Plasma Physics Corporation, P.O. Box 548, Locust Valley, NY 11560; 516-676-8468
Mr. John H. Coleman, Principal Investigator
Mr. John H. Coleman, Business Official
DOE Contract No. DE-AC02-87ER80457
Amount: \$49,782

Silicon nitride powder has substantial advantages over other ceramic powder for applications such as cutting tool inserts, rotary shafts for turbines, and engine valves. Consequently, the market demand is expected to increase from 250,000 lbs to 2.5 million lbs annually by 1995, provided an economic production process is developed. Thus, successful results on the present project could result in substantial energy savings in the future. A novel, supersonic, two-stage plasma reactor is planned for efficiently producing high density silicon nitride powder from silane and ammonia. Ammonia is dissociated in the first novel reactor by a high current, low pressure plasma, and dissociated fragments are injected into the second stage through the nozzle at near Mach 1 velocities to convert thermal energy of the fragments into directed kinetic energy. A second plasma region activates the reaction between the activated ammonia fragments and the silane. The long reaction zone will favor homogeneous reactions in the gas phase and nucleation favoring the formation of particles. In the event technical and economic feasibility is established, the use of silicon nitride will enable higher thermodynamic efficiencies and substantial energy savings.

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

include cutting tool inserts, turbine rotors, and automotive valve shafts.

15

Deposition of Metastable Thin Film Materials by Light-Assisted Metalorganic Chemical Vapor Deposition—Spire Corporation, Patriots Park, Bedford, MA 01730; 617-275-6000

Mr. Christopher Keavney, Principal Investigator
Mr. Richard Gregorio, Business Official
DOE Contract No. DE-AC02-87ER80491
Amount: \$49,821

It is planned to grow metastable semiconducting phases, including alpha-tin and cubic tin-germanium alloys by light-assisted metalorganic chemical vapor deposition. Precursors such as tetramethyl tin, germane, or tetramethyl germanium will be introduced into a reactor. As the gases flow past the substrate, ultraviolet light will illuminate them through a quartz window, and the photolysis will generate free radicals that will deposit on the substrate. The use of light to dissociate the gas molecules will allow epitaxy to be carried out at a lower temperature than would normally be the case for chemical vapor deposition. This lower temperature may be crucial for maintaining metastable materials in the desired phases. In Phase I, the photolysis of various metalorganic compounds will be investigated to establish the feasibility of the process. The influence of light intensity, substrate temperature, and other variables will be established. If photolysis and deposition of metals from these compounds is successful, Phase II will be concerned with establishing the conditions needed for epitaxial growth.

Anticipated Results/Potential Commercial Applications as described by the awardee: If the planned three-phase project is successful, a new technique will become available for the formation of metastable semiconducting materials with properties or combinations of properties not found in currently available materials. This research will result in a greater understanding of metastability and crystal growth in general. In addition, commercialization of the results (through the manufacture and sale of deposition equipment) will widen the availability of metastable thin films. Among the possible practical applications

that could result from this are new types of lasers, infrared detectors, and abrasion-resistant coatings.

16

Synthesis of Inorganic Films by Ion Beam Irradiation of Organosilicon Polymer Films—Universal Energy Systems, Inc., 4401 Dayton-Xenia Road, Dayton, OH 45432; 513-426-6900

Dr. Daniel Yuan-Fu Yu, Principal Investigator
Mr. Larry E. Clay, Business Official
DOE Contract No. DE-AC02-87ER80448
Amount: \$49,904

This research program is directed toward a novel technique to convert organometallic polymer films into useful ceramic films by ion beam irradiation. A select group of organosilicon polymers that can be converted into SiC, Si₃N₄, Si₂ON₂, and SiO₂ will be synthesized. Thin polymer film on silicon substrate will be prepared by spin-on methods. This process has several advantages over other conventional deposition methods. The viscosity of polymer solution can be adjusted easily by solvents so as to be ideal for thin film preparation. These polymeric materials can be initially processed like an organic polymer and subsequently converted to inorganic films. The resultant film compositions can be modified easily by using various organometallic polymers. The thin polymer film will be subjected to ion beam irradiation. High energy ion beam irradiation of the polymer film can dissociate the polymer into smaller fragments, and organic volatile fragments will diffuse through the film and escape. Any element that is not removed in the form of volatile species is subsequently enriched with respect to the other elements. The conversion (removal of volatile organic component) can be accomplished at relatively low processing temperatures. Inorganic films prepared by this method are expected to be denser and more adherent to the substrate than those produced by conventional thin film techniques.

Anticipated Results/Potential Commercial Applications as described by the awardee: This study is expected to result in a technically viable and commercially attractive processing methodology for fabrication of ceramic thin films such as SiC, Si₃N₄, Si₂ON₂, and SiO₂.

Amorphous Ferromagnetic Material with Ultra-Low Eddy Current Losses—Xi Magnetics, Inc., R. D. 4, Box 457, Coatesville, PA 19320; 215-347-1768
 Dr. John L. Wallace, Principal Investigator
 Dr. John L. Wallace, Business Official
 DOE Contract No. DE-AC01-87ER80486
 Amount: \$50,000

Commercially available amorphous magnetic materials prepared by rapid quenching from the melt are restricted in thickness to the range of approximately 0.5 mils to 5 mils and cannot be formed directly onto substrates. Many prior workers have used sputtering to deposit small samples of amorphous thin films, but the required targets containing large amounts of metalloids tend to be fragile and expensive. An alternative method of thin film deposition will be developed, which will be well suited to reliable manufacturing without sacrificing any of the versatility required in R&D activities. This method can be used to deposit amorphous magnetic materials directly onto substrates for monolithic integrated devices, but it will also lend itself to the deposition of thick multilayered stacks on thin substrate tapes.

These tapes could then be wound into toroids and used for fast risetime magnetic modulators, VHF/UHF inductors, and the like. The Phase I effort will set up the necessary equipment, deposit thin multilayered samples with chemical composition similar to Metglas®, measure the high frequency magnetic properties of the samples, and determine their physical structure and chemical composition.

Anticipated Results/Potential Commercial Applications as described by the awardee: This research should result in improved and less expensive, multilayered, microlaminated, ferromagnetic composites that, in turn, will be applicable to pulsed laser power supplies, particle accelerators, kinetic energy devices, pulsed x-ray sources, fusion research, UHF programmable attenuators, high-Q VHF/UHF resonators or inductors or phase shifters, UHF/VHF fast RF switches, inductive energy storage, EMP simulators, EML technology, and recording heads. However, there also would be many applications for monolithic amorphous magnetic films in a single-layer format such as torque sensors, solar systems, magnetometers, recording media underlayers, transducers, anti-theft systems, EMI shielding, biomedical sensors and implants, and current sensors.

ADVANCED CONTROL SYSTEMS

A Vision-Augmented Control System for Robotic Manipulators—Expert-EASE Systems, Inc., 1301 Shoreway Road, Belmont, CA 94002; 415-593-3200
 Mr. Steve Engle, Principal Investigator
 Mr. Bjorn Frogner, Business Official
 DOE Contract No. DE-AC03-87ER80464
 Amount: \$49,918

The development of a vision-augmented control system for robotic manipulators is planned. The system employs a novel structure, which places the vision system camera on its own manipulator arm, allowing the camera to seek positions of optimal visibility for control of coarse-to-intermediate manipulator movements. Furthermore, it permits the camera to use multiple views from different perspectives to

gain additional information. Robustness is added to the system by including prior knowledge, such as electronic blueprints, of the environment within which the manipulator arms operate. The vision system thus serves as a driver for the dynamic programming algorithms that provide spatial planning and control of the robot manipulator arms.

Anticipated Results/Potential Commercial Applications as described by the awardee: The planned research has far-reaching potential uses in applications of robotic systems that could benefit from increased levels of autonomy. Such systems include underwater recovery craft, spaceborne telepresence systems, and robots used to perform sampling and inspection activities in the containment vessels of nuclear power plants or other hostile environments.

PLANT NATURAL PRODUCT CHEMISTRY

19

Preparation of Monoclonal Antibodies to Plant-Derived Oligo- and Polysaccharides—Complex Carbohydrate Corporation, Suite 512; 2351 College Station Road, Athens, GA 30605; 404-546-7797
Dr. Michael G. Hahn, Principal Investigator
Dr. Alan Darvill, Business Official
DOE Contract No. DE-AC05-87ER80507
Amount: \$50,000

The purpose of this research project is to generate monoclonal antibodies that recognize defined epitopes on oligo- and polysaccharides of plant origin. Such antibodies will be useful for purifying plant-derived oligo- and polysaccharides, providing structural information about the carbohydrates to which the antibodies bind, and determining the tissue and cellular distribution of the carbohydrates. The

feasibility of generating such monoclonal antibodies will be examined in Phase I. Hybridoma cell lines that secrete monoclonal antibodies to rhamnogalacturonan-I, a plant cell-wall derived polysaccharide, will be generated. The complete structure of the epitope recognized by at least one of the antibodies will be determined. These studies will be extended in Phase II to include characterization of epitopes recognized by other anti-rhamnogalacturonan-I antibodies and generation and characterization of monoclonal antibodies to additional plant-derived oligo- and polysaccharides.

Anticipated Results/Potential Commercial Applications as described by the awardee: Production for the commercial sale of monoclonal antibodies recognizing defined epitopes on a variety of plant-derived poly- and oligosaccharides is expected in Phase III of this program.

HEALTH AND ENVIRONMENTAL EFFECTS INSTRUMENTATION

20

A Rainfall Measurement Device Using Underwater Acoustic Signals—Creare, Inc., P.O. Box 71, Etna Road, Hanover, NH 03755; 603-643-3800
Dr. Frederic Laville, Principal Investigator
Dr. James A. Block, Business Official
DOE Contract No. DE-AC01-87ER80478
Amount: \$49,173

Measurements of rainfall over large bodies of water such as large lakes or oceans are made infrequently because of the lack of an accurate measuring device. A large portion of the Earth's precipitation falls over the oceans; therefore, it is essential for understanding global climate to have accurate measurements of rainfall over large water areas. A device will be developed to measure rainfall accurately by using underwater acoustic signals. The basic principle of this device is digital processing of the underwater acoustic signal generated by rainfall to determine its intensity. The principle has been derived theoretically and demonstrated experimentally. However, there are important limitations in the method used, and it

is planned in this project to establish more sophisticated signal-processing techniques to overcome these limitations. Specifically, our goal is to improve significantly the accuracy of the measurements: whereas the actual state of the art yields rainfall rate estimates within a factor of 2 of the actual value, the goal of Phase I is to show the feasibility of signal processing techniques that will yield estimates with measurement errors no greater than 20%. The feasibility study will include theoretical and experimental work. Phase II will include the development of a prototype device and its testing under actual conditions, and Phase III will be devoted to the development of a commercial device that will allow for easy measurements of rainfall over large bodies of water.

Anticipated Results/Potential Commercial Applications as described by the awardee: The result of this three-phase development program will be a device that could be easily deployed on the surface of an ocean or large lake to measure accurately the rate of rainfall.

NUCLEAR MEDICINE

21

A Three-Dimensional Display for Emission Computed Tomography—Aerodyne Products Corporation, 76 Treble Cove Road, North Billerica, MA 01862; 617-663-7411

Mr. David E. Willoughby, Principal Investigator
Dr. Gerald W. Stewart, Business Official
DOE Contract No. DE-AC01-87ER80476
Amount: \$49,976

The object of the planned research is to demonstrate the feasibility of producing a true three-dimensional (3-D) display for viewing the imagery produced by emission computed tomography systems in the field of medicine. The ultimate objective is to display hard and/or soft copy computer-generated holograms very rapidly. During Phase I of the program, a Holographic Display Instrument (HDI) will be improved by adding a Spatial Light Modular (SLM). This will permit improved picture quality and faster writing. Using a data base corresponding to a simple 3-D surface, the computer-driven HDI will be used to create hard copy 3-D images of the surface. This effort will define those parameters that contribute to bright, low noise holographic images. The SLM should produce displays with resolutions of 10 million voxels or more. In Phases II and III, the 3-D displays at this resolution will be produced in color. The interface between emission-computed tomography systems and the HDI will be developed as will the critical interface with the user.

Anticipated Results/Potential Commercial Applications as described by the awardee: It is anticipated that a true 3-D display will result, capable of rapidly displaying 3-D imagery that is stored or available as a digitized data base. Such a device will have commercial applications in medical imaging, seismology, computer-assisted design, and a number of other fields. Previous analyses indicate a potential market by 1995 of well in excess of \$50 million per year for a successful computer-generated 3-D holographic display.

22

A New Photon Detector for Single Photon Emission Computer Tomography and Positron Emission Tomography—Applied Research Corporation, 8201 Corporate Drive, Suite 920, Landover, MD 20785; 301-459-8442
Dr. Andrzej K. Drukier, Principal Investigator

Mr. Andrew S. Endal, Business Official
DOE Contract No. DE-AC05-87ER80510
Amount: \$49,439

Development of a novel type of particle detector is planned based on energy-sensitive superconducting structures. In Positron Emission Tomography (PET)/Single Photon Emission Computed Tomography (SPECT) application it promises order of magnitude improvements in image quality because of (1) submillimeter spatial resolution; (2) very fast, subnanosecond readout; and (3) very high stopping power for high energy photons. The possibility of development of a new ring detector that features both SPECT and PET imaging capability is suggested.

Anticipated Results/Potential Commercial Applications as described by the awardee: The planned new photon detector should permit considerable improvement of PET/SPECT images. It has the potential for reducing costs of PET and/or SPECT devices.

23

A New Low Cost, Compact Cyclotron for Positron Emission Tomography Using a Superconducting Magnet—Computer Technology and Imaging, Inc., 810 Innovation Drive, Knoxville, TN 37922; 615-966-7539

Mr. George Hendry, Principal Investigator
Dr. Ronald Nutt, Business Official
DOE Contract No. DE-AC05-87ER80516
Amount: \$50,000

This project is aimed at designing a light weight and compact negative ion cyclotron using a superconducting magnet. The planned cyclotron will cost 25% less than existing resistive magnet cyclotrons, will occupy 50% less space, and will weigh approximately 4000 lbs compared with 40,000 lbs for the conventional cyclotron. The new cyclotron operating expense will be slightly less than the operating cost for the conventional cyclotron. The helium cost of the superconducting magnet is more than offset by the electrical cost of the conventional cyclotron. This superconducting concept for a medical cyclotron will use already developed shielding technology, targets, and ion source technology. Thus, the design goal will be to build a cyclotron that will occupy a space of 1 m diameter by 1.5 m high, weighing 4000 lbs and capable of producing curie quantities of ^{11}C , ^{15}O , and ^{18}F and 300-400 mCi of ^{13}N ammonia.

Anticipated Results/Potential Commercial Applications as described by the awardee: The market for clinical Positron Emission Tomography (PET) is developing rapidly since many of the barriers have been addressed. This planned design makes possible a light weight transportable PET center similar to existing transportable imaging centers. In addition, the small size and light weight remove existing constraints that the PET Center must be located on a ground floor of the hospital. With the improvement in cost and size, the market for the new cyclotron is expected to be 20 to 30 units during the first year of production.

24

Radiolabeled Antibody Fragments for Abscess Imaging—RhoMed, Inc., 1020 Tijeras NE, Suite C, Albuquerque, NM 87106; 505-256-0595
Dr. Buck A. Rhodes, Principal Investigator
Mr. Stephen A. Slusher, Business Official
DOE Contract No. DE-AC03-87ER80542
Amount: \$50,000

A method to discover high concentrations of white blood cells in the human body is essential to determine the location of infections of unknown origin (occult abscesses) and for other conditions. Present methods are expensive, time-consuming, and require significant technical expertise. This project will involve preparation of a radiopharmaceutical for use in detecting occult abscesses and other conditions in

which there is a high local concentration of white blood cells. Fragments of monoclonal antibodies that bind to human leukocytes or leukocyte subsets will be prepared in a kit to facilitate their rapid radiolabeling with sodium pertechnetate Tc-99m. The radio-labeled antibody fragments will then be used for the in-vivo tagging of white blood cells. Monoclonal antibody 80 H.3, which reacts with the Fc receptor of human granulocytes, will be evaluated for this use along with several other commercially available monoclonal antibodies. Other monoclonal antibodies will be used as the nonspecific control in experiments that test the binding of candidate antibodies. The initial evaluation will measure the ex-vivo binding to a series of samples using small aliquots of cells that are otherwise being labeled for clinical use by the present method of In-111 labeling of whole white blood cells.

Anticipated Results/Potential Commercial Applications as described by the awardee: The aim is to develop a safe, effective and simple kit for radiolabeling monoclonal antibody fragments with Tc-99m for imaging white blood cell concentrations. The primary use is for detection and localization of occult abscesses (fevers of unknown origin), but other applications exist, such as evaluation of inflammation at surgical or joint replacement sites and for radioimmunoguided surgery. A significant and growing market for this type of product exists. The product under development will be simpler, more cost effective, and, because of the imaging provided by Tc-99m, technically superior.

HEALTH AND ENVIRONMENTAL EFFECTS METHODOLOGIES

25

Chemiluminescent Labels for Polynucleotides Electrophoretically Separated in Agarose Gels—DURA Research Products, P.O. Box 815, Cheshire, CT 06410; 203-272-4190
Dr. Edward M. Davis, Principal Investigator
Dr. Edward M. Davis, Business Official
DOE Contract No. DE-AC01-87ER80468
Amount: \$50,000

This project is to develop a nonradioactive method for labeling genetic materials. A light-emitting chemical reaction (chemiluminescence) will be employed as a label. Chemiluminescence, owing to its high sensitivity, simplicity, and safety, provides an alternative to radioisotopes. This new labeling

technique is expected to find use in medical chemistry and biotechnology research laboratories and in teaching settings at universities and high schools. In addition, development work will begin for imaging, recording, processing, and storage of experimental genetic data obtained with chemiluminescent labels.

Anticipated Results/Potential Commercial Applications as described by the awardee: New chemiluminescent labels will be developed to visualize, quantitate, and record genetic materials. These new labels could replace many of the hazardous labels, such as radioisotopes and ethidium bromide, now widely used in genetic engineering. They may also surpass the detection limits attained with radioisotopes. Many

new products are anticipated to be developed including chemiluminescent labeling kits for genetic materials, a Polaroid film image recording device, and most important, a light-sensitive digital imaging system to record and later process data collected from chemiluminescent-labeled genetic materials.

26

A Microcomputer-Based DNA Gel Electrophoresis Image Analysis—Genetics Data Services, Inc., 3150 South Babcock Street, University Plaza, Suite O, Melbourne, FL 32901; 305-768-2048

Dr. John C. Hozier, Principal Investigator

Dr. John C. Hozier, Business Official

DOE Contract No. DE-AC05-87ER80506

Amount: \$37,894

This project is to design and construct a microcomputer-based instrument for quantitating size distributions of nucleic acids (DNA and RNA) separated according to size by gel electrophoresis. The starting point for analysis of fluorescence-stained DNA in gels will be the image digitization of the entire gel electrophoretic pattern (or specified portions of it) so that the relative intensities of fluorescence will be converted directly to image data in computer memory. Once the gel fluorescence image has been digitized, the image processing system will perform quantitative measurements of the amount of DNA of various sizes using semiautomated comparison to DNA size standards. Advantages of such a system include flexibility, precision, and reliability in the analysis; acceptance of varying formats for gel electrophoresis; and because the system is microcomputer-based and probably can be assembled from stock components, relatively low cost. Phase I will focus on investigations of hardware component requirements, assembly of a preliminary hardware design to demonstrate feasibility of the planned configuration for a workable gel-digitization analysis instrument, as well as initial software development to demonstrate the potential analytical utility of such a system. Phase II will then involve construction, thorough testing and validation of the overall hardware system design, and complete generation of a software system for the accurate and versatile analysis of DNA size distributions on gels. System design will provide the broadest and most versatile set of DNA analytic functions possible, to accommodate new applications in molecular genetics, gene mapping and sequencing, and genetic toxicology.

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

application is an imaging system that records fluorescence intensity directly in digital form to measure damage inflicted on DNA by UV and ionizing radiation. Although this application of DNA gel electrophoresis is addressed specifically in this project, the microcomputer-based DNA size analysis system that is to be developed will have broader applications to gel electrophoresis of nucleic acids including gene mapping and sequencing, and medical diagnostics. Since DNA gel electrophoresis is one of the basic technologies associated with these molecular genetics applications, there should be a wide commercial market for a well-designed and cost-effective system for quantitating DNA patterns.

27

An Improved Imaging System Using a CCD Detector to Quantitate Fluorescence from Stained DNA Gels—Instrumentation Development, Inc., 25 Nimitz Place, Old Greenwich, CT 06870; 203-637-2010

Dr. Stephen A. Myers, Principal Investigator

Dr. Stephen A. Myers, Business Official

DOE Contract No. DE-AC01-87ER80471

Amount: \$49,581

The mass of DNA separated by gel electrophoresis can be determined from the intensity of the fluorescence of a DNA-specific dye excited by UV radiation. The present use of photographic film to record the fluorescence limits the accuracy, sensitivity, and dynamic range of the analysis. Alternate scanning systems that directly detect the fluorescence are slow. A new imaging system is planned to measure both the mass and the molecular weight of the sample. Substantial instrumental improvements appear possible in fluorescent excitation, optical light collection and imaging, and detector performance. Replacing film with a charge-coupled array detector (CCD) now appears attractive because of recent improvements in CCD performance and the availability of larger arrays at lower cost. Those optical properties of the stained DNA/gel system will be measured, which must be well-characterized to design a high performance imaging system and to estimate its performance with useful accuracy. An engineering analysis of a specific design will examine the increased analytical ability to quantitate the mass of DNA in a band through improved fluorescence measurement, and whether the overall measurement time can be significantly shortened by achieving high detector signal-to-noise and by more fully automating the measurement. The Phase I study will address the feasibility of the new instrumental approach, estimate the limits of performance, and provide a design direction for the prototype hardware to follow in Phase II.

Anticipated Results/Potential Commercial Applications as described by the awardee: Improved performance, greater speed, and the prospect of increased automation will greatly extend the use of this imaging fluorescent assay technique, both for nucleic acid and for other applications in gel electrophoresis. Broader uses may include other biological systems requiring low light level imaging of fluorescence or phosphorescence. New quality control or clinical applications are possible.

28

An Image Acquisition and Processing System for the Analysis of Fluorescence from Stained DNA Gels—
KMS Fusion, Inc., P.O. Box 1567, 3853 Research Park Drive, Ann Arbor, MI 48106-1567; 313-769-8500
Mr. Ron McKean, Principal Investigator
Mr. Robert F. McCarthy, Business Official
DOE Contract No. DE-AC02-87ER80445
Amount: \$48,804

Evaluation of damaged DNA components is normally performed via agarose gel electrophoresis of DNA samples stained with fluorescing dye. Although this method provides adequate sensitivity and resolution in the identification of DNA components, the lack of available instrumentation to convert the fluorescing image into a digitized record for computer entry and the lack of any technique for standardizing analyses performed under varying conditions severely limit the usefulness of this analysis. The goal of this project is to develop an instrument that makes it possible to digitize stained DNA gels directly into any computer (via a standard communications interface),

standardize the results, and perform statistical analysis of the data. This instrument will quickly scan the gel using an optical system that has high photometric resolution and very high spatial precision. The digitized data will then be electronically preprocessed (background subtraction, filtering, data compression, etc.) to provide correct, noise-free data structured for storage with minimal memory requirements. The stored data will then be available for use in imaging the gel, producing statistical comparisons, and generating graphic displays. The data will be archivable using media such as magnetic tapes or disks. This instrument will offer a solution to problems long associated with agarose gel analysis of DNA. The direct quantification of fluorescence in stained DNA gels will allow immediate access to the data by a computer, instantly providing such information as average molecular weight. The instrument will enable direct comparison of separate analyses performed under varying conditions, allowing for complete normalization of results and generation of statistical data involving many individual tests.

Anticipated Results/Potential Commercial Applications as described by the awardee: An instrument will be developed that should be capable of reproducibly and accurately determining the amount of pyrimidine dimer formation within samples of DNA. The instrument will be very useful in medical and research applications (particularly as a clinical tool for monitoring individuals who have been exposed to acute or chronic dosages of UV light) and for testing the effects of various chemical agents in either repairing or damaging DNA. It is anticipated that the instrument will evolve to an efficient clinical DNA analysis station.

HIGH ENERGY PHYSICS TECHNOLOGY AND RESEARCH

29

A Cryocooler Stage for Operation Between 20 and 4 K—
Alabama Cryogenic Engineering, Inc., P.O. Box 2451, Huntsville, AL 35804; 205-536-8629
Dr. John B. Hendricks, Principal Investigator
Dr. John B. Hendricks, Business Official
DOE Contract No. DE-AC05-87ER80458
Amount: \$49,942

The development of a liquid helium temperature cryocooler is planned. A regenerative cryocooler will provide a 20 K temperature sink of a Joule-Thomson (J-T) stage using helium. An innovative design for the

J-T stage heat exchangers will allow the use of simple, hermetic compressors, which will make a portable, long lifetime unit possible. The study will focus on systems having a cooling power of less than 10 mW at 4.2 K. This refrigeration load would be approximate for superconducting sensors, such as the Superconducting Quantum Interference Device (SQUID).

Anticipated Results/Potential Commercial Applications as described by the awardee: If successful, this cryocooler would make the application of superconducting electronics possible in portable units. Simple operation and long lifetime would make operation by nonspecialists possible.

Research and Development of Multisegment Ceramic Ring Cryogenic Seals—Aspen Systems, Inc., 184 Cedar Hill Street, Marlborough, MA 01752; 617-481-5058

Dr. Kang P. Lee, Principal Investigator
Dr. William M. Toscano, Business Official
DOE Contract No. DE-AC01-87ER80474
Amount: \$50,000

The major limiting reliability component of cryogenic systems has always been seals. Besides contributing to gas contamination and debris particle accumulation, seals have failed physically. As a result, seals have been responsible for the majority of cryogenic liquefaction and refrigeration system failures. A potentially viable solution is the development of a multisegment ceramic ring cryogenic seal employing hard-on-hard wear-resistant materials combination, that is, an unlubricated hard material sealing against another hard material with minimal ensuing wear. This approach has been utilized before for seals on machinery operating in both abrasive and extreme-temperature environments. The Phase I primary objective is the laboratory testing of a prototype cryogenic seal promising 30,000 hours mean time between failures (MTBF) and suitable for integration with cryocoolers. Divided into four tasks, Phase I includes final analyses, design and fabrication of the laboratory prototype seal, design and fabrication of the laboratory test system, and laboratory testing of the seal at ambient and cryogenic temperatures. The anticipated results are the measurement of the thermodynamic performance and reliability of the cryogenic seal, experimental verification of the seal analytical design tools, and preparation of design drawings of the cryogenic seal integrated with an off-the-shelf cryocooler.

Anticipated Results/Potential Commercial Applications as described by the awardee: Except for a very few cases, cryogenic refrigeration and liquefaction systems have always been primarily support systems for other major technologies, and the cryogenic systems have been unreliable in relationship to the total systems. Consequently, the major benefit, though indirect, of the planned R&D of long-life cryogenic seals is the rapid acceptance and/or increased market viability of several new high technology areas, for example, superconducting power generation and transmission systems; advanced superconducting

computers; cryopumps; cryocoolers for instrumentation; airborne and spacecraft applications; small, dedicated laboratory cryogenic systems; and nuclear magnetic resonance systems for medical applications.

Miniature Electromagnetic Bearings for Cryogenic Applications—Creare, Inc., P.O. Box 71, Etna Road, Hanover, NH 03755; 603-643-3800

Dr. Herbert Sixsmith, Principal Investigator
Dr. James A. Block, Business Official
DOE Contract No. DE-AC01-87ER80477
Amount: \$49,902

There is a strong need for high efficiency cryogenic compressors, which can pump modest vacuum levels to reduce the temperature of the liquid helium used in cooling superconducting magnets below 4.2 K. Although highly reliable and contamination free, self-acting gas bearings cannot operate reliably at temperatures below 70 to 100 K or pressures below about 0.4 atm. Hence, the use of gas bearings in a low pressure, ultra-low temperature compressor requires that the bearings operate at higher temperatures and pressures, with the concomitant efficiency penalty associated with heat and flow leakages. An attractive alternative to gas bearings for this application is the use of electromagnetic bearings. Magnetic bearings can operate at any temperature and pressure, down to hard vacuum. However, present magnetic bearing technology is not suitable for application to high-speed miniature turbomachinery. This project describes a novel electro-optical position sensing system that will allow control of high-speed miniature magnetic bearings. Phase I of this project will assess the feasibility of the concept by demonstrating a breadboard optical sensing system. If proven feasible, the magnetic bearings would be demonstrated in Phase II by building and testing a prototype cryogenic vacuum compressor.

Anticipated Results/Potential Commercial Applications as described by the awardee: In addition to the cryogenic compressor application described above, magnetic bearings are also ideally suited for applications in miniature cryogenic turboexpanders. Room temperature applications of an oilless magnetic suspension system include long-life motors and clean helium compressors. Reliable magnetic bearings would also have widespread application in inertial navigation systems and other long-life rotating equipment for space.

High-Speed, High-Resolution Ultrasonic NDT/E of Superconducting Magnet Mono- and Multifilamentary Wire—Sonoscan, Inc., 530 East Green Street, Bensenville, IL 60106; 312-766-7088

Michael G. Oravec, Principal Investigator

Dr. Lawrence W. Kessler, Business Official

DOE Contract No. DE-AC02-87ER80453

Amount: \$50,000

Development of an ultrasonic, nondestructive test device for inspection of monofilament rod and potentially multifilamentary wire for superconducting magnets is the long-term goal of this project. The rod and wire to be inspected are the high critical-current conductors used in high field magnets planned for particle accelerators. There is no established technique for detecting flaws in small diameter (less than 0.5") rod or wire. This technique provides great leverage by finding problems at an early, low cost point in the manufacturing process. To provide internal inspection, monitor interface continuity, inspect the rod surface for defects, and monitor layer thickness, the inspection system must combine Scanning Laser Acoustic Microscopy (SLAM) techniques with high frequency pulse-echo techniques. For practical scanning times for 30-foot-long rod and quantities of one million pounds over several years, high-speed signal processing and data acquisition will be required. Phase I will examine the feasibility of 10-100 MHz frequencies for internal inspection of the superconducting core and stabilizer cladding in monofilament rod for inclusions and voids (size greater than 3% of core diameter and 5% of cladding thickness). SLAM optical and acoustic imaging will be examined for monitoring rod surface defects. A focused, 50-100 MHz pulse-echo system will be developed for monitoring barrier and stabilizer layer thicknesses, uniformity, and continuity. The close coordination of the two detection techniques, data acquisition, and signal processing for rapid scanning time will be detailed. The device's usefulness for multifilamentary wire will be considered.

Anticipated Results/Potential Commercial Applications as described by the awardee: An outcome of this research will be the development of a technique for nondestructive examination of superconducting wire and its constituent rods for defects. The wire is needed for superconducting magnets in particle accelerators and nuclear magnetic resonance imaging. Similar wire is needed in superconducting magnets for plasma fusion confinement systems, such as mirror confinement and tokamaks.

Electrically Conductive Polymers by Ion Implantation—Spire Corporation, Patriots Park, Bedford, MA 01730; 617-275-6000

Dr. Ih-Huang Loh, Principal Investigator

Mr. Richard Gregorio, Business Official

DOE Contract No. DE-AC02-87ER80450

Amount: \$49,936

The Phase I program will investigate the creation of an electrically conductive surface layer on several types of nonconductive polymer sheet. The conductivity will be measured and correlated to ion implantation parameters such as ion species, dose, and energy. Any changes or improvements in the mechanical, chemical, or optical properties as a result of ion implantation will also be investigated. Additionally, the program will assess the feasibility of treating large areas of production quantities of polymeric sheet using present ion implantation equipment. The successful Phase I program will delineate specific ion beam formulations for creating controlled conductivity on several commonly used polymers. The use of conductive polymeric sheeting has several applications in the design of high energy particle detectors. The ability to create a surface layer of known resistivity (conductivity) on a highly resistive polymer or composite sheet is very desirable.

Anticipated Results/Potential Commercial Applications as described by the awardee: The ability to create an electrically conductive surface selectively and controllably on a polymer sheet is expected to impact significantly the design and manufacture of particle detectors. The construction of a facility for ion implantation of polymer sheet should greatly enhance and simplify the manufacture of these detectors and should positively contribute to the microelectronics, battery, and photovoltaics industries.

The Effect of Different Levels of Manganese on Mechanical Properties and Coupling—Supercon, Inc., 830 Boston Turnpike, Shrewsbury, MA 01545; 617-842-0174

Dr. Eric Gregory, Principal Investigator

Ms. Elaine Drew, Business Official

DOE Contract No. DE-AC01-87ER80437

Amount: \$49,995

At fields of 0 to 0.3 T, as used in the Superconducting Super Collider injection field, coupling between NbTi filaments in fine filamentary composites has

been found to occur in some materials. This is particularly true when the interfilamentary spacing falls below $0.35\text{ }\mu\text{m}$ and the matrix material is high purity copper. Several methods of reducing this coupling have been planned and some are being investigated. These methods fall into two principal groups: those that operate by suppressing the mean free path of the electrons, a route that leads to a high resistivity solid solution alloy matrix (e.g. CuNi) and those that employ electron-spin-flip scattering by solute ions carrying localized magnetic moments (e.g. Mn). It can be shown theoretically that Mn can be an order of magnitude more effective than nonmagnetic solutes in reducing the penetration distance of super electrons. Although relatively small percentages of Mn in copper may be effective in reducing the coupling, the effect of a range of Mn levels on the fabricability of these alloys, particularly when in the form of a composite with NbTi, needs to be determined. In Phase I, the effectiveness of Mn in reducing coupling will be explored. In addition, the effect of various levels of Mn on the mechanical and electrical properties of the Cu alloys without the presence of NbTi will be determined. In Phase II, full size multifilamentary composites will be made with various selected CuMn alloys and the effects observed on fabricability, stability, and coupling.

Anticipated Results/Potential Commercial Applications as described by the awardee: We expect that this work will result in a significant property improvement in fine filamentary NbTi superconductors by allowing closely spaced filaments, with accompanying high J_c 's, without coupling. The material will be suitable for a wide range of applications including dipoles and quadrupoles for future high energy accelerator magnets.

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Optimization of Properties of Ductile Superconducting Alloys for Operation up to 10 T—Supercon, Inc., 830

Boston Turnpike, Shrewsbury, MA 01545;
617-842-0174

Dr. Eric Gregory, Principal Investigator

Ms. Elaine Drew, Business Official

DOE Contract No. DE-AC01-87ER80438

Amount: \$50,000

Recently, significant improvements in J_c 's of NbTi fine filamentary wire have been achieved at fields of 5 to 8 T in materials with both fine and coarse filaments, but questions have been raised as to the ductility and piece lengths that can be achieved commercially in the fine filament wires with the highest J_c 's. The factors affecting piece length and ductility in wires containing both sizes of filaments will be investigated. Recently, there has been an increased interest in material for 10 T dipoles and an optimization of the high J_c material at fields of 10 T will be carried out. Testing will take place at temperatures below 4.2 K, and both binary NbTi and two ternary NbTiTa alloys will be investigated in Phase I, if the NbTiTa material can be obtained quickly enough. Otherwise only the binary alloy will be optimized. In Phase II the work at 10 T and low temperatures on both ternary and binary alloys will be continued and scale-up of the processes to commercial size billets will be undertaken to ensure that ductility is not adversely affected.

Anticipated Results/Potential Commercial Applications as described by the awardee: It is anticipated that this investigation will determine the factors that govern ductility and piece length in high J_c , fine filament, NbTi material, and it will enable establishment of commercially viable specifications for future accelerator magnet materials. It is also expected that the work will yield both technical and economic information from which a decision can be made as to the viability of NbTi or NbTiTa as materials for 10 T dipoles and quadrupoles.

HIGH ENERGY PHYSICS DATA PROCESSING AND DETECTOR INSTRUMENTATION

36

A Parallel Associative Computer for High-Speed Execution of Logic Programs and Expert Systems—
Coherent Research, Inc., 719 East Genesee Street,
Syracuse, NY 13210; 315-424-1135

Mr. Charles D. Stormon, Principal Investigator

Mr. Charles D. Stormon, Business Official

DOE Contract No. DE-AC02-87ER80501

Amount: \$49,524

Symbolic computation (especially logic programming) will play an increasingly important role in both experimental and theoretical physics. Logic programs are also important in their application to expert systems, which are in increasing use by the utility industry. As these expert systems become more complex, and as they are used in time-critical applications, their computational requirements outstrip the capabilities of today's computers. It is believed that very high performance can be obtained on a machine of modest cost, by use of novel Very Large Scale Integration (VLSI) associated memory architectures. This optimism is supported by preliminary studies and simulations. This study determines the feasibility of a high performance Prolog engine based on content addressable memory and a Reduced Instruction Set Computer designed for multiprocessing (the transputer). The project includes the results of an instrumented simulation and of a VLSI design study. Expected performance is in excess of 1,000,000 logical inferences per second.

Anticipated Results/Potential Commercial Applications as described by the awardee: This study should show the feasibility of a workstation-based Prolog engine with sufficient computational power to model complex physical systems and run large expert system programs with rapid response time. This system should foster progress in the use of logic programming in the utilities industry as well as by physicists.

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A High-Performance Disk Controller for the FASTBUS—Digital Video Processing, Inc., 7841
Epsilon Drive, Rockville, MD 20855; 301-670-9282

Mr. Matthew W. Price, Principal Investigator

Ms. Maria Cristina Valeiras, Business Official

DOE Contract No. DE-AC05-87ER80461

Amount: \$50,000

The FASTBUS is a standardized, high-performance 32-bit bus used in data acquisition and distributed processing systems. There are currently several manufacturers who are building boards that are compatible with the FASTBUS and use many of the possible features. Additionally, R&D is continuing in private industry, universities, and the government to support the FASTBUS standard for various new logic modules. One major area that is not receiving support, however, is the interfacing of mass storage devices (such as Winchester, optical, floppy disks, or tapes) directly to the FASTBUS. The project will involve examining several of the current mass storage device interfacing requirements for applicability to the FASTBUS, after which the throughput and protocol requirements of the FASTBUS will be mated with the special interface needs of commercial off-the-shelf storage devices. To ascertain the feasibility of the planned research, special capabilities of the FASTBUS, such as multiprocessing, high-speed burst mode transfers, and physical and logical storage addressing will be considered in the design of the flexible, high-performance FASTBUS disk controller module. It is foreseen that the planned module will offer an order-of-magnitude increase in performance over current disk interface techniques.

Anticipated Results/Potential Commercial Applications as described by the awardee: The planned research effort will, for the first time, allow users of FASTBUS-based systems to connect directly mass storage devices (such as rigid disks, tapes, and WORM drives) to the FASTBUS. Current systems require limited indirect access to these mass storage devices. The planned interface capability will extend the usefulness of the FASTBUS by reducing costs while simultaneously improving system performance. A high-performance disk controller module allowing standard devices to directly interface to the FASTBUS would be a timely item for the system integrator. An OEM disk interface module would thus be popular in existing FASTBUS systems, and would help create a commercial market for the FASTBUS where it has not been previously suited.

New VME-FASTBUS Interfacing Alternatives—
KineticSystems Corporation, 11 Maryknoll Drive,
Lockport, IL 60441; 815-838-0005

Mr. Michael J. Skubic, Principal Investigator

Mr. Robert T. Cleary, Business Official

DOE Contract No. DE-AC02-87ER80446

Amount: \$49,993

Because of the rapidly increasing demands on data acquisition and computer processing systems in most DOE-funded research today, FASTBUS has become a vital presence in high energy physics projects worldwide. Similarly, because of its broad flexibility and international character, VMEbus is emerging as a popular host and post-processing environment. Although some systems have been designed that allow communication between FASTBUS and VMEbus, none take full advantage of the wide range of communication modes that are possible with these bus structures. This project suggests that with the proper knowledge of these bus structures, current interface technology, and the specific needs of the prospective users of these systems, a more widely accepted and powerful FASTBUS to VMEbus interface could be designed. To this end a detailed study of FASTBUS and VMEbus specifications will be carried out. A study of available VME-FASTBUS interfaces will provide important knowledge about the strengths and limitations of the current technology. A survey of users, especially in the high energy physics community, will yield valuable information about their particular requirements for such a device. Then, all of this information will be used to determine a desired set of interface features. The feasibility of incorporating these features into one of several general models will be judged. On the basis of this judgment, a detailed description of the planned device will be submitted along with a block diagram indicating the device's functional elements and their interconnections. Finally, appropriate Phase II development will be recommended.

Anticipated Results/Potential Commercial Applications as described by the awardee: The successful completion of this study will result in a detailed description of a FASTBUS interface to VMEbus, which will be designed to utilize the inherent strengths of each bus structure as well as accommodate the specific needs of the high energy physics community. The subsequent manufacture and availability of this device would provide a critical link in the computer instrumentation requirements of many ongoing and planned DOE-funded research projects.

Large, Thin, Flat, Full-Color Displays for Graphics Display Units—Lucitron, Inc., 1918 Raymond Drive,
Northbrook, IL 60062; 312-564-8383

Mr. Michael DeJule, Principal Investigator

Dr. Alan Sobel, Business Official

DOE Contract No. DE-AC02-87ER80489

Amount: \$49,955

There is a great need for improved displays to deal with massive amounts of data from complex experiments. Even with a great deal of computer manipulation, the results must be presented to the experimenter in comprehensible form. This is best done using high-resolution color graphics. The display should be large enough so that a group of experimenters can work with it and interact with each other, and it should be bright enough so that they can do this in a reasonably well-lit room, enabling them to consult notes and other material. Work is planned to improve the resolution of SuperSize™ flat, thin, bright, full-color FLATSCREEN® Gas-Electron-Phosphor (GEP) display panels. They will be window-glass-flat, real-time video displays, 4 ft² or larger, and only 3-in thick. Such devices also can be used in other applications: powerplant and process control, teleconferencing, command and control, computer-aided design and manufacturing, training, and education, among others. Compared with projection systems, FLATSCREEN® panels will be less bulky and therefore more portable; they will be brighter, clearer, have wider viewing angles, and will not require focus or convergence adjustments. They can be far larger and much lighter than direct-view CRTs, and they have no geometrical distortion due to deflection nonlinearity or faceplate curvature. FLATSCREEN® panels are effectively flat, matrix-addressed, multiple-beam CRTs, with all the flexibility in application of the CRT but in a larger and more convenient package.

Anticipated Results/Potential Commercial Applications as described by the awardee: This work will provide the foundation for improving the resolution of FLATSCREEN® displays to 30 pels/in or better. Window-glass-flat displays of this resolution in sizes of 4 ft² and larger will have applications wherever computer or TV data must be used by groups of people. They will compete effectively with projectors and large CRTs, and be far more convenient to use than either. It is anticipated that this could lead to a substantial U.S. manufacturing business within 6 years, with further rapid growth thereafter.

The Development of an Intelligent VAXBI FASTBUS Interface—NYCB Real-Time Computing, Inc., 18 Meudon Drive, Lattingtown, NY 11560-1025; 516-759-0707

Dr. Eric J. Siskind, Principal Investigator

Dr. Eric J. Siskind, Business Official

DOE Contract No. DE-AC02-87ER80455

Amount: \$49,896

An intelligent list-processing interface between the VAXBI and FASTBUS will be developed. The VAXBI is the 13.3 megabyte/sec backplane interconnect featured in VAX 8200, 8300, 8800, and other future VAX computer systems. The intent is to provide a high bandwidth gateway between a variety of VAX configurations, including single processors, multiprocessors, and clustered processors, and the FASTBUS. The hardware consists of a FASTBUS interface, a VAXBI interface, and one or more processors providing the interface intelligence. The FASTBUS interface uses either one of a pair of plug-compatible FASTBUS cards being developed. A high bandwidth card implemented in ECL 2500 gate macrocell arrays has been developed as well as a compatible interface in TTL PAL and IFL technology. The VAXBI interface will be either a DRB-32 VAXBI module with modified microcode, a future VAXBI I/O processor interface provided by Digital Equipment Corporation, or a custom VAXBI interface to be designed in Phase II. Intelligence will be provided either by a microprocessor in the future DEC I/O processor or by an outboard 16-bit microprocessor. Besides the usual support for a FASTBUS interface, software development will focus on three major areas: (1) the mapping of virtual memory, which must be provided by interfaces on a physically addressed I/O bus such as the VAXBI; (2) methods of sharing a single FASTBUS interface among multiple processors on a single VAXBI; and (3) the possibility of providing transparent access to a single FASTBUS interface to all members of a VAX cluster.

Anticipated Results/Potential Commercial Applications as described by the awardee: A direct means of connecting the FASTBUS to the latest generation of VAX processors will be available to allow the use of these and future processors in experiments in elementary particle physics and in other disciplines requiring the use of FASTBUS. At present, the only means of connecting an intelligent FASTBUS interface to a VAXBI-based processor is via an intervening Unibus, which has the disadvantages of both reducing bandwidth to the 0.6 megabyte/sec Unibus bandwidth and of incurring the additional cost of a VAXBI-to-Unibus adapter.

The Bulk-Storage Module for FASTBUS Memory Applications—Scientific Systems International/Modular Software Systems, Inc., 3491 B Trinity Drive, Los Alamos, NM 87544; 505-662-6712

Mr. Donald R. Machen, Principal Investigator

Mr. Donald R. Machen, Business Official

DOE Contract No. DE-AC02-87ER80454

Amount: \$50,000

The FASTBUS system specification for high energy physics and other data system applications defines a large address space in which support modules may reside on connected segments. The increasing number of experiments in the physical sciences using FASTBUS dictates that the spectrum of support modules must continue to grow and be extended in capability. At present, the variety of FASTBUS memory modules and the scope of their functions are limited. Features of the FASTBUS protocol have not been effectively used to help increase the available data storage space and performance for large memory configurations. A Bulk-Storage Module (BSM) will be developed having comprehensive functions to serve as a standard memory element for FASTBUS applications. The BSM will contain at least 8 megawords of high-speed storage that can easily be upgraded as the semiconductor industry increases the density of its memory-integrated circuits. Additionally, the BSM will feature memory-interleaving and histogramming capabilities that use the FASTBUS protocol to achieve a many-fold increase in both speed and storage capacity within a FASTBUS system. An interleaved BSM memory system could easily reach a capacity of 512 megabytes per crate, comparable to the size of disk drives installed on many host computer systems. The feasibility determination that will be made during the Phase I research will include a system design of the BSM; selection of the initial memory element to provide at least an 8-megaword, 32-bit error-corrected memory in a configuration that will allow the module to be upgraded easily; and development of interleaving and automatic histogramming techniques for a BSM that uses the FASTBUS protocol to gain speed and overall capacity.

Anticipated Results/Potential Commercial Applications as described by the awardee: It is anticipated that the unique features of the BSM will make it an essential memory element in the data-acquisition systems for FASTBUS-supported experiments now in planning stages at major accelerator laboratories in the United States and elsewhere. As a buffer, the BSM will offer unusual flexibility; moderate performance for small, single-module applications; and full FASTBUS speeds for large, interleaved

configurations. As a histogramming memory, the BSM can eliminate the necessity of recording all events for off-line data reduction. The simplicity of the design will translate directly into system reliability, maintainability, and lower cost, making the BSM attractive to members of the physics community and other potential FASTBUS users.

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High-Speed, Long-Distance Gateways Among VMEbus, CAMAC, and FASTBUS Backplanes—Synetics Corporation, 80 Main Street, Reading, MA 01867; 703-848-2550

Mr. R. A. Fastring, Principal Investigator

Mr. Martin Wapner, Business Official

DOE Contract No. DE-AC01-87ER80473

Amount: \$46,490

A considerable technology base for data acquisition and control has been built around the international Computer Automated Measurement and Control (CAMAC) backplane bus. A new instrumentation backplane standard called FASTBUS has been developed under the sponsorship of DOE. The European and U.S. data processing and display communities have widely accepted the VMEbus backplane standard. To provide interoperability between older

instruments built to CAMAC standards, newer devices built to FASTBUS, and general purpose data processing equipment built to VMEbus, gateways among these three backplanes are needed. Furthermore, long distance gateways that can span campus-wide or facility-wide multiple laboratories/control rooms are needed to effectively integrate larger experiments or process control applications. This task will provide the design and architectural tradeoffs for high throughput, low delay gateways among these three backplane standards via the high-speed fiber optic Local Area Networks (LANs) under development by the American National Standards Institute (ANSI) Fiber Distributed Data Interface (FDDI) and by the Society of Automotive Engineers (ASE) AE9/b High Speed Ring Bus (HSRB).

Anticipated Results/Potential Commercial Applications as described by the awardee: The successful completion of this task will provide designs of useful long-distance backplane extenders that will provide an effective migration path for CAMAC technology into the FASTBUS environment, with the added benefit of tying in the hundreds of CPU, memory, disk controller, and related boards currently available in VMEbus format. These devices would be of interest to the entire CAMAC, FASTBUS, and VMEbus user communities.

PARTICLE ACCELERATOR TECHNOLOGY

43

Microwave Power Output Coupling and Transport in a Two-Beam Accelerator—DULY Consultants, 1912 MacArthur Street, Rancho Palos Verdes, CA 90732; 213-548-7123

Dr. David U. L. Yu, Principal Investigator

Dr. David U. L. Yu, Business Official

DOE Contract No. DE-AC03-87ER80529

Amount: \$49,795

This research will investigate the feasibility of and techniques for extracting microwave power from a free electron laser using a septum coupler and for transporting the RF wave to feed a high gradient structure in a two-beam accelerator. Numerical simulations will be used to study the geometric effects of the waveguides and the effects of thermal load on the mode conversion and phase stability of

the transported RF wave. Methods of controlling these effects will be proposed to maintain the TE₀₁ mode and to minimize undesirable phase shifts in the microwave during extraction and transport. The methodology developed in this research will be used as a basic design tool for the coupling waveguides to improve the efficiency of the two-beam accelerator. Possible applications to the relativistic klystron also will be investigated.

Anticipated Results/Potential Commercial Applications as described by the awardee: The results of the research will be applied by system designers to improve and optimize the coupling waveguide in a two-beam accelerator. The coupling waveguide will provide an efficient means for extracting and transporting energy from the low energy power source to the high gradient accelerating structure.

An Investigation and Development of the Collective Interaction Klystron—Mission Research Corporation, 5503 Cherokee Avenue, Suite 201, Alexandria, VA 22312; 805-963-8761

Dr. John Pasour, Principal Investigator
Mr. Donald A. Schafer, Business Official
DOE Contract No. DE-AC05-87ER80522
Amount: \$48,572

An experimental, theoretical, and numerical program is planned to develop and study a novel, high-power microwave source, the Collective Interaction Klystron (CIK). This device promises to be a highly efficient, compact source in the 1-to 10-GHz range, and alternate configurations that extend the operation to higher frequencies are possible. Linear theory predicts very high growth rates and strong electron bunching in the device, which is similar to a conventional two-cavity klystron but with a curved drift space. Enhanced bunching caused by the negative mass instability occurs in the drift region. An initial numerical simulation of the device, which exhibits an order of magnitude faster bunching than could be achieved in a linear system, has been performed. With the electron beam parameters chosen (1 MeV, 2 kA), a two-cavity CIK should be capable of GW-level operation at an efficiency of 50%. If the output cavity is replaced with a quasi-optical open resonator, the device could possibly be operated at significantly shorter wavelengths.

Anticipated Results/Potential Commercial Applications as described by the awardee: This program is designed to produce an efficient, high-power, narrow band, compact microwave source that would be quite attractive for advanced RF accelerators as well as other applications. A better understanding of circular charged particle devices, which could be of great interest in the stabilization of cyclic accelerators, should also result.

A High Field Gyrotron-Driven Source of Multiply Charged Ions—Spire Corporation, Patriots Park, Bedford, MA 01730; 617-275-6000

Dr. Ward Halverson, Principal Investigator
Mr. Richard Gregorio, Business Official
DOE Contract No. DE-AC02-87ER80451
Amount: \$49,076

The program will investigate use of the recently developed gyrotron tube for driving high field electron cyclotron resonance (ECR) sources of highly charged heavy ions. Gyrotrons can produce many kilowatts of continuous RF power at frequencies between 30 and 300 GHz (wavelengths between 10 and 1 mm) at efficiencies of up to 30%. The short wavelengths of the gyrotron allow ECR resonance at higher magnetic fields than in present klystron-driven ion sources and offer the potential for compact and intense sources of highly charged ions. The Phase I research will investigate the frequency scaling of ECR-driven sources for multiply charged heavy ions and address theoretical questions on plasma generation; heating and confinement; absorption of RF power at the fundamental resonance and higher harmonics; ion extraction; and engineering problems of RF coupling, heat transfer, materials, and costs. A preliminary design will be made in preparation for final design, construction, testing, and evaluation of a prototype gyrotron-driven ECR ion source in a Phase II research program.

Anticipated Results/Potential Commercial Applications as described by the awardee: Successful completion of the program through Phase III should result in the development of a very high brightness source of multiply charged heavy ions, which should be compact and very efficient. The ion source would have immediate applications in particle accelerators for nuclear physics research. An intense source of highly stripped ions would also have commercial applications for deep ion implantation of semiconductors, metals, ceramics, and plastics at relatively low acceleration voltage.

NUCLEAR PHYSICS INSTRUMENTATION AND TECHNIQUES

46

A Boron Phosphide Semiconductor Neutron Detector—Radiation Monitoring Devices, Inc. and Devcom, Inc./Joint Venture, 44 Hunt Street, Watertown, MA 02172; 617-926-1167

Dr. Gerald Entine, Principal Investigator

Dr. Gerald Entine, Business Official

DOE Contract No. DE-AC01-87ER80440

Amount: \$49,721

Since their discovery neutrons have remained one of the most difficult forms of radiation to detect. The most effective neutron detectors in current use are gas filled detectors employing either ^3He or BF_3 as the detection medium. Unfortunately, gas filled detectors suffer from a number of deficiencies including large size (gases have low volumetric efficiency for stopping neutrons), mechanical fragility, and high voltage measurements. We propose to develop a new form of solid state neutron detector from the semiconducting compound boron phosphide. Boron phosphide possesses most of the desirable electrical

properties of similar III-V compounds, which have allowed production of semiconducting detectors from GaAs and InP. Because boron phosphide is a solid that contains boron as a stoichiometric component, it has a high stopping efficiency for thermal neutrons. Useful crystals of boron phosphide are very difficult to obtain due to their high melting point. Recently, however, researchers have been able to grow thick films on silicon substrates by chemical vapor deposition methods. It is planned to use similar techniques to grow BP/Si heterojunction diodes capable of efficient neutron detection. Neutron detectors made from boron phosphide would be vastly superior to the gas detectors currently in use and may also be extremely promising for building arrays of detectors with high spatial resolution.

Anticipated Results/Potential Commercial Applications as described by the awardee: The planned neutron detector would find widespread usefulness in replacing conventional neutron detectors, particularly where a small, rugged detector is needed.

PLASMA DIAGNOSTICS

47

Improved Sensitivity and Selectivity in Collector Probe Experiments by Analysis with Resonance Ionization Spectroscopy—Atom Sciences, Inc., 114 Ridgeway Center, Oak Ridge, TN 37830; 615-483-1113

Dr. Norbert Thonnard, Principal Investigator

Dr. Harold W. Schmitt, Business Official

DOE Contract No. DE-AC05-87ER80515

Amount: \$49,892

In the fusion energy program, collector probes are an important tool for characterizing and understanding the particle fluxes and energies in the plasma edge. The energy of the ions and neutral atoms impinging on these probes is quite low, thereby leaving most of the particles close to the probe surface. Depth profiling of the collected material gives information about the particle energy, and density measurements give information about the flux at the probe site. Probe samples are analyzed with

multiple techniques including RBS (Rutherford backscattering), NRA (nuclear resonance analysis), and SIMS (secondary ion mass spectrometry). These techniques are often complementary, with data required from all three to get reliable information. SIMS data give good depth profiles, but are not quantitative. Time-resolved measurements are becoming more important, but may be limited for minor (but important) impurities in the plasma because of the short exposure time. Sputter Initiated Resonance Ionization Spectroscopy (SIRIS) has the potential for being quantitative, having good depth profiling capability, and also being far more sensitive for all elements than present techniques. During Phase I, we will adapt the SIRIS technique to the special requirements of plasma diagnostics. Development of instrumentation enabling rapid analysis of probe samples at plasma facility sites is planned during Phase II.

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

capable of quantitative depth profiling for any element with essentially equal high sensitivity and good depth resolution would be of great value to researchers at magnetic confinement fusion facilities. Such an instrument would allow fast turnaround for diagnostic tests and improved time resolution because of its higher sensitivity. Instrumental properties that are of value to plasma diagnostics would also be of value to the field of surface science and to semiconductor research, development, and fabrication.

48

An Optical Fiber Current Sensor for Plasma Diagnostics—EOTec Corporation, 420 Frontage Road, West Haven, CT 06516; 203-934-7961
Dr. Mokhtar S. Maklad, Principal Investigator
Dr. David A. Krohn, Business Official
DOE Contract No. DE-AC01-87ER80442
Amount: \$48,689

This project addresses the need for magnetic field and current measurement devices for fusion plasma diagnostics, especially in the Compact Ignition Tokamak (CIT). Fiber optic magnetic field sensor development is planned to take advantage of the high sensitivity, high temperature, radiation resistance, and dielectric properties of the optical fiber. The high sensitivity and large dynamic range will be achieved by twisting low birefringence single mode fiber enhanced with a high Verdet constant core material. The twist-induced circular birefringence quenches the environmental fluctuations and increases device sensitivity. To monitor the spatial field distribution, a point sensor will be developed employing high Verdet constant crystals. The temperature stability of the optical fiber and crystal will be studied and optimized. The feasibility of distributed point sensing around the vacuum vessel will be addressed. Optical fiber sensors have many distinct advantages over conventional techniques; among them are small size and deployment versatility, high sensitivity and accuracy, resistance to high temperature and radiation environment, and inherent safety and immunity to electromagnetic and radio frequency interference. These sensors should perform well in high radiation fields, high magnetic fields and high temperature plasma environments. The technique measures current directly, which simplifies data reduction.

Anticipated Results/Potential Commercial Applications as described by the awardee: Plasma diagnostics for CIT or ATF (the Advanced Toroidal Facility) to study weapons effects on systems, basic weapon physics, and exploring plasma fusion as an energy

source will be enhanced using fiber optic sensors. The small size and high sensitivity allow application in the CIT and accelerators. They can be used in power utility applications such as current measurement and in high voltage power generating and transmitting stations. These sensors also can be used as zero radar cross section high sensitivity electromagnetic detectors.

49

The Development of Shielded X-ray Plasma Diagnostic Detectors for High Radiation Backgrounds—Radiation Science, Inc., P.O. Box 293, Belmont, MA 02178; 617-494-0335
Dr. Allen S. Krieger, Principal Investigator
Dr. Allen S. Krieger, Business Official
DOE Contract No. DE-AC02-87ER80495
Amount: \$49,993

X-ray diagnostic instruments are convenient for defining such plasma parameters as the electron temperature, ion temperature, density, and impurity concentration as a function of position within a magnetically confined plasma. There is, however, a need to protect the instrument from the adverse effects of the plasma under study. Some x-ray detectors and dispersing elements can be damaged or destroyed by the radiation environment associated with fusion experiments. In addition, sensitive detectors can be subject to very high background counting rates. Many of the standard x-ray plasma diagnostic instruments are unable to withstand the radiation background of TFTR (the Tokamak Fusion Test Reactor), CIT (the Compact Ignition Tokamak), or future fusion reactors. The solution is to design instruments in which the sensitive components are shielded from the fusion environment while the x-ray flux is conveyed to them. This can be accomplished through the use of x-ray-transmitting fiber optics. X-ray fiber optics are broadband, compact, and highly directional. It is therefore possible to design detectors that are insensitive to the high radiation background. To prove the concept, this project will develop a radiation-resistant detector assembly for the SOXMOS (soft x-ray monochromator-spectrometer) at TFTR.

Anticipated Results/Potential Commercial Applications as described by the awardee: This project will explore the value of using x-ray-transmitting fiber optics to suppress background radiation by building the first in a family of radiation-resistant plasma diagnostic instruments for fusion research. X-ray fiber optics also will be useful in inertial confinement fusion diagnostics and in other areas where x-ray or

extreme ultraviolet radiation must be detected in the presence of harmful background radiation. X-ray-transmitting fiber optics also may prove useful in transferring x-ray radiation between vacuum environments that must be kept isolated. Ultimately, x-ray fiber optics may prove as useful to x-ray technology as conventional fiber optics have proven at longer wavelengths.

50

A Novel Optical Concept for Rapid Scanning Two-Dimensional Thomson Scattering—Science Research Laboratory, Inc., 15 Ward Street, Somerville, MA 02143; 617-547-1122

Dr. Reich Watterson, Principal Investigator
Dr. Jonah Jacob, Business Official
DOE Contract No. DE-AC01-87ER80472
Amount: \$49,527

Knowledge of the electron temperature and density throughout the cross-section of a plasma fusion device is needed for detailed understanding of its performance. Present Thomson scattering techniques, which employ a fixed optical arrangement, are capable of providing simultaneous measurements of the electron temperature and density at multiple locations along a single path traversed by a laser beam through the plasma. Future noncircular tokamaks, such as Alcator C-MOD and CIT (the Compact Ignition Tokamak), are expected to have asymmetric temperature and density profiles but to be operated

for long steady-state periods. Switching the optical path to be followed by a 50-Hz Nd:YAG laser during the 20-msec-period between pulses and properly designing the Thomson scattered light collection optics would enable two-dimensional electron temperature and density profiles to be determined within a single tokamak discharge. A synchronously positioned optical element (e.g., a mirror) would direct the beam along separate, nearly vertical chords for successive laser pulses. Techniques to simultaneously direct the laser beam and collect the scattered light reliably from a two-dimensional array of locations using a limited number of spectrometers will be evaluated. In addition, important issues that must be considered in designing spectrometers for the high temperatures (5-10 keV) expected in next-generation tokamaks will be evaluated.

Anticipated Results/Potential Commercial Applications as described by the awardee: The development of a fast-scanning two-dimensional Thomson scattering system would provide the fusion community with a diagnostic tool uniquely suitable for the next generation of compact, noncircular tokamaks. There is a clear need for a temperature and density diagnostic with the high spatial and temporal resolution achievable by Thomson scattering techniques. Such a two-dimensional Thomson scattering system would be applicable to Alcator C-MOD and CIT and would provide fusion experiments with a valuable and cost-effective diagnostic not likely to be provided by other techniques.

PLASMA CONFINEMENT SYSTEMS TECHNOLOGY

51

A Microwave Ion Source for Remote Leak Detection and Vacuum Analysis Instrumentation for Fusion—Applied Science and Technology, 37 Cedar Street, Newton, MA 02159; 617-253-8154

Dr. Donald K. Smith, Principal Investigator
Mr. John M. Tarrh, Business Official
DOE Contract No. DE-AC01-87ER80475
Amount: \$49,779

Presently available mass spectrometer-based vacuum instruments are not suitable for use in anticipated fusion facilities, where tritium will be used. The ion source is the primary limitation. This R&D program will lead to development of a miniature ECR (Electron Cyclotron Resonant) microwave ion source for application in leak detectors and vacuum

instrumentation. The ECR ion source can be developed in a very rugged compact form that will provide very long source lifetime and immunity to damage from pressure excursions and active gases. The ECR ion source eliminates the filaments and other internal electrodes that limit the lifetime and operating environment of other ion sources. Leak detectors and mass spectrometers based on this new source will tolerate reactive gases and high pressures during operation. In Phase I the feasibility of the ECR ion source for leak detectors will be addressed. This will include designing a prototype source and testing the low power ECR source concept. Feasibility will be assessed considering both the source and an associated solid-state microwave driver. In Phase II a prototype instrument will be developed and properties of the ECR source investigated in detail.

Anticipated Results/Potential Commercial Applications as described by the awardee: The development of a compact ECR ion source for mass spectrometer-based vacuum instrumentation will provide the ruggedness and reliability required for remotely maintained, tritium-using facilities. It is anticipated that a compact ECR ion source can ultimately replace the filament type sources in the commercial vacuum instrumentation market. This will provide higher reliability and improved sensitivity for leak detectors and gas analyzers.

52

Gate Valves for Fusion Applications—Radial-Directed, Fluid-Pressure-Loaded, All-Metal-Sealed Double Gates—Batzer and Associates, 1191 Canton Avenue, Livermore, CA 94550; 415-447-8804
Mr. Thomas H. Batzer, Principal Investigator
Dr. Ralph W. Moir, Business Official
DOE Contract No. DE-AC03-87ER80537
Amount: \$50,000

The development of a fusion reactor-compatible valve should make a significant contribution toward providing vacuum hardware for next-generation tritium-burning devices and should find application in semiconductor manufacturing industries and elsewhere. It is planned to design in Phase I and build and test in Phase II a series of large gate valves up to 1 m diameter that meet the following characteristics: (1) double gate seals that can be differentially pumped; (2) an actuating mechanism that is not required to provide the gate-seal loading; (These two points result in a large weight (hence cost) savings.) (3) a valve body that is not required to react to the gate-seal loading because of radial-directed seal force; (4) scaling that is limited only by the atmospheric loading of the gate plates; (5) a gate shape that is not necessarily round; (6) operability with a minimum number of limited size particulates because of the use of a double gate with differential pumping; (7) a leak rate (undifferentially pumped and barring foreign bodies of too large a size) that becomes asymptotic to a specified level after a number of closure cycles; (8) no organic materials so the valve will be tritium compatible and radiation hardened.

Anticipated Results/Potential Commercial Applications as described by the awardee: The results of Phases I and II should be a gate valve that can be used in fusion devices that use tritium and have a radiation environment, in the semiconductor manufacturing industry where high purity and speed of operation steps are important, and in the ion implantation industries. The Phase II work in cooperation

with a valve manufacturing company should facilitate putting this valve into production. The planned Compact Ignition Tokamak (CIT) device might be the first use of this valve, should it be developed.

53

Cost-Effective Techniques for Development of Radiation-Resistant Organic Insulators for Superconducting Magnets—Composite Technology Development, 2705 Regis Drive, Boulder, CO 80302; 303-494-8999

Dr. Maurice B. Kasen, Principal Investigator
Dr. Naseem A. Munshi, Business Official
DOE Contract No. DE-AC02-87ER80487
Amount: \$49,916

An approach to composite materials development is planned that reduces substantially the cost of conducting studies required to optimize materials selection for demanding service conditions. Although applicable to many areas of advanced composite materials development, the approach is optimized for efficient development of the component materials performance data base that is required for fabrication of radiation-resistant composite insulators for use in the superconducting magnets of magnetic fusion energy systems. The approach is based upon in-house production of composite specimens in the form of 3.2 mm diameter rods that can be tested directly in flexure, in short-beam shear, in torsion, or for fracture energy at cryogenic temperatures before and after irradiation. Techniques already exist for producing the required specimens from epoxy resins. The main thrust of this project is to extend the specimen-preparation technique to advanced polymer types, such as polyimides, polyphenylene sulfide, and polyether-etherketone, that have higher intrinsic resistance to radiation degradation but require more sophisticated processing techniques. During Phase I it is planned to focus on condensation-type and additive-type polyimides and to demonstrate that high-quality specimens reinforced with graphite and aluminum oxide fibers as well as glass can be produced with such resins and efficiently tested at cryogenic temperatures.

Anticipated Results/Potential Commercial Applications as described by the awardee: Some possible benefits are (1) cost reduction and increased reliability in development of composite materials for use in the cryogenic portions of magnetic fusion energy systems and (2) development of a procedure for establishing a data base that will permit selection of optimum components for maximum performance and

reliability. Another important benefit would be development of a cost-effective, integrated approach to composite materials performance evaluation that will facilitate the rapid introduction of advanced composite technology into the aerospace, automotive, and other industrial fields.

54

A Hypervelocity Pellet Injector—InterScience, Inc., 105 Jordan Road Troy, NY 12180; 518-283-7500
Dr. James T. Woo, Principal Investigator
Dr. James T. Woo, Business Official
DOE Contract No. DE-AC01-87ER80441
Amount: \$49,611

To achieve precise shaping of density profiles in fusion reactors with pellet fueling, injection velocities of up to 10 km/sec may be required for pellets of a few milligrams in mass. Present pellet injectors based on the pneumatic gun or centrifuge principles are capable of attaining velocities of about 2 km/sec, and the basic concepts do not appear to be easily scalable to higher performances. A new concept for projectile acceleration by electromagnetic compression was previously developed. The concept is based on well-established principles and technologies and is presently being developed for potential kinetic energy weapons. It is shown that by applying this concept to the acceleration of deuterium pellets of a few milligram mass, velocities approaching 10 km/sec can be attained in a distance of 1 to 2 m. The components and technology required to attain this level of performance also are relatively modest. A program is planned to apply this principle to the design of a facility that can meet the pellet injector requirements for reactor fueling. The design can be modularized for implementation in stages from proof-of-principle demonstration to full operation on a major fusion plasma confinement experiment.

Anticipated Results/Potential Commercial Applications as described by the awardee: The results of the Phase I effort will lead to the definition of a specific design and a program plan for the development of a pellet injector that can meet the projected requirements for fusion reactor fueling. The design can be implemented under Phase II to develop an operational system that can be installed on a major fusion plasma confinement facility for pellet fueling.

55

The Development of NbN-Coated Graphite Superconducting Materials—Material Concepts, Inc., 666 North Hague Avenue, Columbus, OH 43204; 614-272-5785
Mr. Donald E. Kizer, Principal Investigator
Mr. Kevin Christopher, Business Official
DOE Contract No. DE-AC01-87ER80480
Amount: \$48,588

Niobium nitride (NbN) materials are attractive candidates for very high field magnets. NbN materials have high critical current densities, low sensitivities to strain degradation effects, and good radiation resistance. Multifilament graphite fiber is an ideal substrate on which to deposit NbN because of its high strength, fine fibril diameters, and low coefficient of thermal expansion. Investigators have deposited NbN on multifilament graphite by magnetron sputtering and chemical vapor deposition methods; however, deposition of aluminum or copper stabilizer to levels of about 50 vol % required for realistic magnet applications has not been achieved. In this project it is planned to use a unique titanium/boron chemical vapor deposition/liquid metal infiltration process to activate the NbN-coated graphite surface and to infiltrate with suitable metal to make NbN-coated graphite superconducting material with aluminum or copper stabilizer.

Anticipated Results/Potential Commercial Applications as described by the awardee: The successful conclusion of this project would result in the development of the first practical NbN-coated graphite superconductor.

56

A Feasibility Study for a 5-MW, 300-GHz Quasi-Optical Gyrotron—Physical Sciences, Inc., 603 King Street, Alexandria, VA 22314; 703-548-6410
Dr. Michael R. Read, Principal Investigator
Dr. J. T. Schriempf, Business Official
DOE Contract No. DE-AC05-87ER80523
Amount: \$49,980

High power, cw (continuous wave) sources at frequencies near 300 GHz are needed for electron cyclotron heating in advanced magnetic fusion devices such as the CIT (Compact Ignition Tokamak). Recent

developments in gyrotrons have pushed the state of the art to 100 kW cw at 140 GHz. One megawatt at 140 GHz appears feasible, but near to the limit of the current form of the gyrotron. The quasi-optical gyrotron is a new form of gyrotron in which the standard microwave cavity is replaced by a large optical cavity. The overall configuration of the device and the large cavity are suitable in principle for production of very large powers. The planned study is to determine, through calculation, the feasibility of a 5-MW cw, 300-GHz quasi-optical gyrotron. Emphasis is placed on the study of electron beam generation and propagation and the optical cavity, with the goal of realizing a preliminary design with an efficiency of over 30%. (Theory predicts efficiencies as high as 45%.) Consideration of noncircular geometries for both the electron beam and resonator mirrors is central to the study.

Anticipated Results/Potential Commercial Applications as described by the awardee: The results of Phase I could lead to the development of a high frequency, high power source for auxiliary heating and profile control in advanced magnetic fusion devices. Heating is a critical issue in these devices. If a successful fusion reactor is realized, it could have a major impact on energy production, potentially replacing most fossil fuel burning power plants. In addition, high power millimeter wave sources are of interest for radar and communications.

57

Continuous Extrusion of Nb₃Sn Superconductors—Pyromet, Inc., 5 Commerce Drive, I-95 Industrial Park, Aston, PA 19014; 215-497-1743
Mr. Jaydee W. Miller, Principal Investigator
Mrs. Elaine C. Frieberg, Business Official
DOE Contract No. DE-AC01-87ER80484
Amount: \$49,835

The push for higher field magnets for applications such as fusion machines has driven the search for a cost-effective, reliable manufacturing process for high field, high current density superconductors. The design/process choices that the manufacturer of filamentary composites must make usually require a compromise between current density and piece length. The requirements for superconductor performance, for example the highly deformed microstructures in NbTi composites or the very different mechanical properties of the components in Nb₃Sn composites, place stringent restrictions on the area reduction process. Wire drawing is cost-effective because it can be done semicontinuously; however, the high tensile forces involved are not ideal

for processing composites with widely differing components. Conventional extrusion holds the advantages of large area reduction and compressive forces, but is severely limited in piece length, hence must be done at large diameters. A highly promising alternative appears to be a continuous extrusion process that allows large area reductions using compressive forces, small starting diameters, and unlimited lengths. This study will explore the feasibility of continuous extrusion of distributed Sn Nb₃Sn composites, a demanding material to process because of the use of pure tin along with niobium and copper. The effects of the extrusion ratio, extrusion rate, die angle, and lubricant on the filament quality, metallurgical bonding, and subsequent drawability of the composite will be studied.

Anticipated Results/Potential Commercial Applications as described by the awardee: The feasibility and limits of continuous extrusion of Nb₃Sn superconductors will be determined. This process should be a cost-effective method to produce high filament quality and long lengths in superconducting composites of all types. A production process for distributed Sn Nb₃Sn composites should allow a cost-effective, high J_c and low AC loss conductor to be available for such applications as toroidal and poloidal field coils, AC applications such as motors and generators, and dipole and quadrupole magnets for particle accelerators.

58

Advanced Insulating Coatings for Plasma Confinement Systems—Spire Corporation, Patriots Park, Bedford, MA 01730; 617-275-6000
Dr. Ward Halverson, Principal Investigator
Mr. Richard Gregorio, Business Official
DOE Contract No. DE-AC02-87ER80449
Amount: \$49,901

Electrical insulators in plasma confinement systems can be exposed to an extremely hostile environment, including bombardment by energetic particles, ultraviolet and x-ray radiation, rapid thermal cycling, and high RF and DC voltages. The insulators must operate reliably in this environment and, additionally, must not generate significant impurities that can disturb the plasma radiation balance and stability. The planned program will study the use of ion beam enhanced deposition (IBED) to form insulating refractory coatings of low average atomic number. The IBED technique uses physical vapor deposition with simultaneous bombardment by energetic ions to yield coatings with superior adhesion, crystallinity, morphology, and highly controlled stoichiometry.

The Phase I effort will include deposition and testing of hard, adherent coatings of boron nitride, aluminum nitride, silicon nitride, and alumina. Encouraging results will lead to Phase II in which these and other coating materials will be optimized and tested in a plasma environment.

Anticipated Results/Potential Commercial Applications as described by the awardee: The development of highly adherent, insulating refractory coatings of materials with low atomic number would lead to improved performance of RF plasma heating structures, waveguide windows, high voltage feedthroughs, and other electrical insulators in plasma-confinement systems. Commercial applications include coatings for insulators in plasma-deposition systems, high voltage switching equipment, and protection for insulators in the environment of space.

59

Process Development for Producing Nb₃Sn Multifilament Superconductors of High Current Density—Supercon, Inc., 830 Boston Turnpike, Shrewsbury, MA 01545; 617-842-0174
Dr. Eric Gregory, Principal Investigator
Ms. Elaine Drew, Business Official
DOE Contract No. DE-AC01-87ER80439
Amount: \$49,983

The current methods of fabricating Nb₃Sn multifilament superconductors present various problems. In the conventional bronze process, the low tin (Sn) content of the 13.5-wt% Sn bronze seriously limits the current density and leaves much of the Nb unreacted. The relatively high melting point, higher Sn bronzes have not been used because they are regarded as largely unworkable. Thus, other processes were developed that use either pure tin or low melting point tin-rich compositions (e.g., the internal tin and the distributed tin methods) that force extrusion and drawing to be done warm or cold to avoid melting the tin source. The low temperature working seriously affects fabrication costs and leads to bonding problems. The planned method will use the higher melting, extra-high Sn bronzes, but in a manner that greatly overcomes the workability problem. The higher tin content bronzes will promote higher current densities, shorter reaction times, more uniform Nb₃Sn layers throughout, less unreacted Nb, and more efficient use of the bronze volume in the superconductor. Also, the process will permit use of solid rather than hollow Nb elements, which will be less costly and allow the fabrication of very fine filaments. In addition, the higher melting point of the Sn

bronzes offers the prospect of higher extrusion temperatures, higher extrusion ratios, and faster drawing speeds than are possible with the lower melting point tin sources in other processes.

Anticipated Results/Potential Commercial Applications as described by the awardee: The results of this work are ultimately expected to produce a process for making fine filamentary Nb₃Sn superconductors of potentially greater current density, overall efficiency, and deformability than those made by current methods. The products should find wide applicability throughout the overall field, where more efficient, higher current density superconductors are desired. The applications include high-energy physics, fusion energy, (multipurpose coil applications), and nuclear magnetic resonance applications.

60

The Development of a Process for Making Multifilamentary NbN—Supercon, Inc., 830 Boston Turnpike, Shrewsbury, MA 01545; 617-842-0174
Dr. Eric Gregory, Principal Investigator
Ms. Elaine Drew, Business Official
DOE Contract No. DE-AC01-87ER80436
Amount: \$50,000

Presently, the only superconductor available commercially in significant volume for operation at fields above 12 T, is Nb₃Sn, and it has been shown to be sensitive to irradiation damage and to have very significant strain sensitivity, particularly at high fields. Both of these facts make large high-field plasma confinement magnets costly and difficult to design. NbN has been made in small quantities by several investigators and has been shown not to be subject to the above drawbacks of the present superconducting A 15 compounds. The problem is to scale up an NbN process to one that will make a strand for incorporation into a high field cable-in-conduit conductor (CICC). Physical vapor deposition (PVD) equipment, suitable for the deposition of long lengths of NbN, has been designed and is available, and preliminary attempts to stabilize the deposited filaments have been started. In Phase I it is intended to concentrate on the development of a method of continuously opening and closing the tow of filaments that is compatible with existing equipment capable of performing these other steps. The properties of samples made on the filament tow will also be investigated to determine which operations need further development. In Phase II the several steps will be consolidated to produce long lengths of stabilized NbN strands for use in a high field CICC.

Anticipated Results/Potential Commercial Applications as described by the awardee: It is anticipated that the results of this study ultimately will be the development of a viable commercial process for the production of stabilized multifilamentary NbN strands for use in high field (> 12 T) magnets. Such

strands would be resistant to neutron irradiation and strain effects. They could have many applications, one of which would be incorporation into a CICC such as that envisaged for the Multipurpose Coil (MPC) and the Engineering Test Reactor (ETR) magnets.

FUSION ENERGY SYSTEMS

61

Composite Materials with Low Z, Self-Regenerating Coatings for Fusion First Walls and Limiters—Corium Industries, Inc., P.O. Box 94086, Atlanta, GA 30318; 404-872-5620

Dr. Yung-Woo Lee, Principal Investigator

Dr. A. B. DeWald, Business Official

DOE Contract No. DE-AC05-87ER80508

Amount: \$49,917

The conditions that plasma interactive materials must face in a magnetic confinement fusion device are such that there does not appear to be any single material that possesses all the necessary properties to prevent either contamination of the plasma or early failure of the plasma-side components. Currently used materials will not be satisfactory for long pulse or steady-state operation. The use of coatings has been suggested as a means of resolving the difficulty, but conventional coatings will not survive in a reactor-grade plasma. Self-regenerating materials offer a means by which the diverse requirements of a fusion environment may be met by a single material with a reasonable service life. These materials depend on utilizing the intense thermal and radiation flux of the fusion environment as a means of producing a low-Z coating that minimizes plasma contamination and self-sputtering and at the same time is resistant to light ion sputtering. Ternary composite materials containing a refractory metal, a good thermal conductor, and an alkali metal are capable of providing good melt-layer stability and better sputtering properties than those obtainable with elemental materials or alloys.

Anticipated Results/Potential Commercial Applications as described by the awardee: Sputter-resistant low-Z materials with good melt-layer stability and high thermal conductivity will be developed for fusion applications using ternary composites consisting

of a refractory metal, a good thermal conductor, and an alkali metal. Additional benefits can be obtained by applying these materials to ion beam inertial confinement fusion as an air-stable lithium ion source and as a new material for high-current electrical contacts.

62

Enhanced Thermal Radiation Mechanical Joints—Foster-Miller, Inc., 350 Second Avenue, Waltham, MA 02154-1196; 617-890-3200

Mr. Roger L. Demler, Principal Investigator

Mr. Adi R. Guzdar, Business Official

DOE Contract No. DE-AC02-87ER80499

Amount: \$50,000

Cooling the internals of fusion reactors is largely dependent upon radiation. The high vacuum conditions eliminate convection cooling as an option, and fragile materials and large differential thermal expansions make contact conductance problematic. This research is designed to enhance the radiation rate across mechanical joints in a vacuum environment. Concepts developed for the compliant attachment of hot tiles and heat transfer concepts developed for conduction across joints in spacecraft radiators are combined to address this concern. Analytical models will be developed to cover the range of design variables. In-vacuum tests will be conducted to support the analytical and design efforts.

Anticipated Results/Potential Commercial Applications as described by the awardee: This research phase should demonstrate that significantly higher radiant heat fluxes can be transferred across joints or interfaces than previously believed. This capability would reduce the size of fusion reactor designs and also reduce the size of high temperature heat-rejection systems on space vehicles.

A Tritium Permeation Resistant Polymer Coating—
KMS Fusion, Inc., 3621 South State Road, Ann
Arbor, MI 48106; 313-769-8500
Dr. Richard L. Crawley, Sr, Principal Investigator
Dr. Alexander J. Glass, Business Official
DOE Contract No. DE-AC02-87ER80456
Amount: \$48,844

Polymer materials and coatings are used in tritium secondary and tertiary confinement gas handling facilities, in glove boxes, window gaskets, epoxy paints, and personal protective clothing items such as bubblesuits, gloves, and booties. These materials lack hydrogen barrier properties. The few hydrogen barrier polymers that exist are prone to beta and gamma radiation damage and lose their barrier properties in high humidity. Hydrogen barrier polymers tend to have hydroxyl (-OH) groups in their structure. The effect of incorporation of -OH groups on the barrier properties of plasma polymers will be investigated. Typical highly crosslinked hydrocarbon plasma polymers are radiation resistant, can be made hydrophobic, and can be applied as tough conformal coatings. Three types of hydroxyl-containing plasma polymers will be made, starting from three different precursors. Plasma deposition parameters will be varied to yield the highest number of -OH bonds in each matrix, and IR spectroscopy will be used to determine the bonding and relative abundance of -OH groups in each polymer coating. Plasma polymer coatings containing significant numbers of -OH groups will be deposited into polystyrene microshells and tested for hydrogen permeability using analytical techniques developed for the characterization of inertial fusion targets. These data will be compared with data previously obtained on common plasma polymer coatings containing only C-H bonding. If there is significant improvement in hydrogen gas retention, the coatings will be subjected to tritium exposure and retested for radiation damage effects.

Anticipated Results/Potential Commercial Applications as described by the awardee: It is anticipated that plasma polymers containing oxygen or -OH correctly bonded into the matrix will have significantly reduced hydrogen permeability. Phase II research will determine the nature of the barrier properties of these polymers and optimize the coating deposition process to provide the best barrier polymers possible using this methodology, while retaining the inherent advantages of plasma polymers such as radiation resistance, good adhesion, conformal coating,

optical clarity, and low moisture permeability. It is planned that a conformal polymer coating that is resistant to tritium permeation will be developed. This coating would be deposited on elastomeric glovebox window seal gaskets as a liner, in place of epoxy paints or over them, and on emergency personal protection gear, such as bubblesuits, gloves, and booties to provide some resistance to the penetration of tritium and/or tritiated water.

An In-Vessel Manipulator Concept Demonstration
for the Compact Ignition Tokamak—Remote
Technology Corporation (REMOTEC), 114 Union
Valley Road, Oak Ridge, TN 37830; 615-483-0228
Mr. John R. White, Principal Investigator
Mr. John R. White, Business Official
DOE Contract No. DE-AC05-87ER80460
Amount: \$49,823

The specialized configuration of the CIT (Compact Ignition Tokamak) plasma chamber with its limited access space, high radiation levels, and high vacuum conditions requires the development of special purpose remote-handling equipment. Initial assembly of the vacuum vessel and port plus in-vessel inspection/maintenance of first-wall components, divertor, diagnostics, and radio frequency launcher are to be performed remotely. A key element of the remote-handling equipment is a two-armed electric master-slave manipulator that will be moved through the torus on an articulated boom. The manipulator will be stored within a radiation shielded vacuum chamber when not in use. The purpose of this project is to evaluate a commercially available manipulator and to identify specific material/component changes needed for operation in the severe radiation and vacuum environmental conditions and configuration changes needed to enter and perform effective work within the torus. A demonstration of the commercial manipulator in a full-sized torus sector mockup will be performed. The output of Phase I will be a manipulator concept design acceptable for in-vessel CIT use.

Anticipated Results/Potential Commercial Applications as described by the awardee: Based on the results of this effort, a Phase II proposal will be submitted to perform detailed design, fabrication, testing, and delivery of a prototype manipulator system to the CIT mockup facility. Commercial application of the manipulator is expected in the nuclear, space, and manufacturing (high temperature) industries.

Graphite Reinforced Copper Alloys for Fusion Reactor Applications—Technical Research Associates, Inc., 410 Chipeta Way, Suite 222, Salt Lake City, UT 84108; 801-582-8080

Mr. Joseph K. Weeks, Principal Investigator

Mr. Charles D. Baker, Business Official

DOE Contract No. DE-AC02-87ER80504

Amount: \$50,000

The first wall structure of fusion reactors will be exposed to hot plasmas and high heat fluxes. This research will determine the feasibility of using bidirectional graphite reinforcement in copper alloys to provide a transition between ceramic armor (which provides resistance to the plasma environment) and

a copper containment vessel where the heat of reaction is extracted. After reviewing the current literature on copper-based metal matrix composites, graphite-reinforced copper will be produced. Physical properties will be tested as a function of thermal cycling.

Anticipated Results/Potential Commercial Applications as described by the awardee: This research should lead to the development of copper alloys with high thermal conductivity and low thermal expansion, suitable for bonding to high performance ceramics. In addition to their intended application as part of the first wall structure for fusion reactors, the same technology may be applicable in joining metal and ceramic components for use in ceramic-based heat engines.

ROBOTICS AND REMOTE SYSTEMS TECHNOLOGY FOR NUCLEAR FACILITIES

Robotic Navigation within Complex Structures—Odetics, Inc., 1515 South Manchester Avenue, Anaheim, CA 92802; 714-758-0300

Dr. Timothy L. Larson, Principal Investigator

Mr. Leonard W. Welsch, Business Official

DOE Contract No. DE-AC03-87ER80538

Amount: \$50,000

The purpose of this research is to develop the technologies of semiautonomous navigation for teleoperated devices, which would allow for the use of this feature in the development of robotic devices for application in nuclear facilities using existing sensory equipment (the three-dimensional Imaging Laser Scanner) in a suitable test environment: a terrain testbed. The testbed consists of a computer-controlled gantry system with five degrees of freedom. Mounted on the gantry robot is the Imaging Laser Scanner, which can be moved in three directions over a simulated terrain. The employment of the gantry robot as the robotic vehicle permits a sharper focus on the specific problem being addressed, while maintaining applicability to a broad range of robotic vehicles. Portions of a nuclear power facility will be modeled in the terrain testbed to test the navigation algorithm. Walls and obstructions

such as pipes and machinery will be represented using lightweight, inexpensive materials to allow model reconfiguration for more comprehensive testing. Navigation inside of complex structures can be broken into two major tasks: global path planning and local subpath following. However, Phase I of this project will concentrate on local subpath following algorithm development. The algorithm will determine a position to command the gantry robot to move to, which will be the subpath goal or an intermediate point if any obstacles are sensed that block the path. Through sensory input from the Imaging Laser Scanner, the algorithm will determine alternate routes for the robot to travel until the ultimate destination or goal is achieved.

Anticipated Results/Potential Commercial Applications as described by the awardee: The expected results are the development of the algorithms for semiautonomous navigation of robots in complex structures through the creation and demonstration of the algorithms in a simulated nuclear power plant environment. Applications for the algorithms will be in the continued development of sophisticated devices for their use in existing nuclear facilities and other potentially hostile environments for the performance of a variety of work tasks.

The Effects on Operator Performance of Force Reflection in a Rate Controller—Odetics, Inc., 1515 South Manchester Avenue, Anaheim, CA 92802; 714-758-0300

Mr. Alan Rohrabacher, Principal Investigator
Mr. Leonard W. Welsch, Business Official
DOE Contract No. DE-AC03-87ER80465
Amount: \$50,000

The objective of the Phase I effort is to establish, by means of a directed research effort, the manner in which active force feedback in a rate controller can improve the operability of a teleoperated system in the performance of complex tasks. Considerations such as ease of training, operator fatigue, ability to perform repetitive tasks, and impacts on operator reliability will be among the topics to be discussed as part of this research. Available hardware will be used in this research, augmented by any additional components required for the development of the force reflective rate controller. The testbed manipulator used in the experiments is an already existing, three-degrees-of-freedom arm of a unique design. Closed loop control of the system will be accomplished by the use of existing control algorithms for the arm, with modifications made for the active force feedback component to be added to the control scheme. Emphasis is on achieving increased performance capability with innovative, but low cost, simple and compact technologies. Future application scenarios are for improved mobility and portability of robotic systems and control centers to increase practicality for a broader range of applications.

Anticipated Results/Potential Commercial Applications as described by the awardee: The results of the Phase I efforts will provide the basis for the design of the man-machine interface for a number of cost-effective and versatile teleoperated devices that will use a rate controller with active force feedback. Because rate controllers with active force feedback are not currently available, this effort will lead to the further development and refinement of such devices in subsequent Phases of the research activity. The improvement of the man-machine interface should lead to further dramatic developments in the use of mobile and portable teleoperated machines for the performance of work in hostile environments.

Force Reflection Effects on Operator Performance of Remote Maintenance and Inspection Systems for Nuclear Facilities—Reinhart and Associates, Inc., P.O. Box 9802-173, Austin, TX 78766; 512-458-2522

Mr. John P. Porter, Principal Investigator
Mr. Eugene R. Reinhart, Business Official
DOE Contract No. DE-AC05-87ER80520
Amount: \$50,000

Robotic machines that duplicate the manipulative skills of a human operator are critically needed in commercial nuclear powerplants to reduce operator exposure in high-radiation areas. Robotic systems with force reflection (force information reflected through a control joystick) and three-dimensional visual feedback can improve task performance and reduce fatigue. This research project will use a very low inertia, bilateral, universal remote controller to investigate the effect of various models and levels of force reflection on the performance of manipulative skills tasks important to the nuclear industry. Initially, the relationship of task characteristics to types of force feedback control and of operator strength to levels of force required will be investigated. These test results will be used in developing parameters or definitions of good task performance. Using these parameters, an adaptive force-reflecting control system would then "learn" a specific operator/task combination and would be used to determine if this ability can be transferred to other task learning and performance.

Anticipated Results/Potential Commercial Applications as described by the awardee: Establishing an effective learning algorithm for a low-inertia, universal force reflecting controller module is key to developing an entire family of remote inspection-maintenance-repair systems. Success of this study would lead to the development of a controller module suitable for limited-access situations; for preinspection tasks such as insulation removal, grinding, and polishing, as well as actual inspection processes; and for use in remote systems in various hazardous environments (nuclear, petrochemical, process, defense industry, etc.).

A Radiation-Hard Remote-Imaging System—Visual Interface Corporation, 1917 Coventry Court, Thousand Oaks, CA 91362; 805-495-6837
Dr. Ahmad Amjadi, Principal Investigator
Dr. John Tracy, Business Official
DOE Contract No. DE-AC03-87ER80535
Amount: \$49,458

This project addresses the problem of remote inspection of highly radioactive installations. A remote-imaging system will be constructed that employs coherent fiber optic bundles to transfer an image

from a reflective telescope to a location where standard imaging techniques can be used. This approach differs from other similar approaches in the use here of hollow, fluid-filled fibers. The use of high index of refraction fluid in the fibers provides for confinement of the light in the fiber. The fluid can be continuously replenished by forcing it to flow toward the high radiation end to sweep out the fluid that has been radiation damaged. The feasibility of constructing such a system using a fiber bundle and a simple vidicon-based image acquisition system will be explored. Issues to be addressed include quality of

image transfer, fluid flow rates and pressures required, and analytical projections of comparative radiation hardness.

Anticipated Results/Potential Commercial Applications as described by the awardee: This approach has potential application in any area where inspection of highly radioactive installations or components is required. This includes diagnostic inspection as well as inspections that are an adjunct to other processes, such as welding and maintenance operations.

SENSORS AND MONITORING FOR ADVANCED NUCLEAR REACTORS

70

A Feasibility Study for a Seismic Early Warning System for Nuclear Powerplant Shutdown—ENSCO, Inc., 5400 Port Royal Road, Springfield, VA 22151-2388; 703-321-4478

Dr. Douglas R. Baumgardt, Principal Investigator
Mr. Erik Thamm, Business Official
DOE Contract No. DE-AC05-87ER80521
Amount: \$48,214

A feasibility study will be conducted of a seismic scram-processing system in which P waves from large earthquakes are detected and analyzed in time to initiate a nuclear powerplant core shutdown before the arrival of large, damaging shear wave phases. A prototype seismic scram-monitoring system will be designed and implemented on a SUN 3/160 engineering workstation. In the planned system, seismic data will be recorded by small seismic arrays (< 3-km aperture) located near the expected seismogenic zones. Processing steps will include P phase detection; estimation of arrival time, amplitude, and frequency; frequency wave-number analysis to determine apparent velocity and azimuth; and a script-matching procedure to predict the amplitudes of later arriving shear phases. Frequency wave-number (F_k) measurements of velocity may be used to identify P phases. Azimuth and frequency estimates will be used to locate the source and discriminate between earthquakes and artificial sources such as mine blasts. If the expected ground motions for later-arriving shear phases exceed a threshold deemed unsafe, a seismic scram alert will be given. This processing scenario will be tested using real data from the NORESS (Norwegian Regional Seismic System) array in

Norway. Simulations will be run to determine if seismic scram processing can be accomplished before the arrival of large damaging shear phases at the reactor site.

Anticipated Results/Potential Commercial Applications as described by the awardee: This study should show whether it is possible to monitor P waves from damaging earthquakes and to initiate a scram of a nuclear powerplant reactor in sufficient time before the occurrence of damaging ground accelerations at the reactor site. The prototype developed during Phase I will be the baseline for the more extensive system that will be proposed for Phase II. The Phase II system will provide an added measure of safety to nuclear powerplants in the face of seismic hazards and will reduce reliance on uncertain engineering testing to determine if nuclear reactors can be shut down safely during the occurrence of high ground motions.

71

Fault Prediction and Dimensional Fault Isolation for Fiber Optic Communication Systems—Phoenix Digital Corporation, 2315 North 35th Avenue, Phoenix, AZ 85009; 602-278-3591

Mr. Ronald A. Brown, Principal Investigator
Mr. J. Thomas O'Connor, Business Official
DOE Contract No. DE-AC03-87ER80525
Amount: \$39,622

Safety and reliability of control are foremost considerations for nuclear powerplants. As nuclear powerplant control becomes more distributed with next-generation intelligent sensors, integrated signal

processors, and so forth, the need for more reliable plant-wide communication will become increasingly significant. Because the distributed communication system is the most exposed element in the overall control system, it is the most vulnerable to transient and steady-state radiation. Optical waveguides avoid electrical interference and offer superior overall safety and performance characteristics. However, they are also susceptible to nonrecoverable radiation-induced losses at low-dose radiation levels such as those commonly found in nuclear powerplant environments. During Phase I of this program, a functional design concept will be proposed for a universal communication device that would provide fault tolerant data transmission with integral, real-time optical power measurement and optical fault isolation capability. This would provide continuous real-time monitoring of optical power losses (radiation-induced and others) coincident with data communication throughout the fiber optic communication grid. Failure conditions could be predicted and dimensionally isolated to the precise location in the optical waveguide where the damage has occurred (or to the location of the failed transmitter or receiver). This would

enable predictive maintenance with a high degree of safety, reliability, and efficiency.

Anticipated Results/Potential Commercial Applications as described by the awardee: The anticipated result is improved overall reliability of fiber optic communication in nuclear powerplants by preventive maintenance through fault prediction and dimensional fault isolation. Potential commercial applications exist not only in local area networking and telecommunications but also in dedicated sensors and instruments. Fault prediction capability would add a much higher degree of reliability to local-area network communication systems where any loss of highly critical data transmission is unacceptable. Dimensional isolation of faults in long-line or telecommunications environments would help to efficiently determine the precise location of the failure through miles of conductors, to help expedite repair and minimize downtime. On-line optical power measurement for fault prediction and fault isolation provides a powerful diagnostic feature for minimizing communication downtime and mean-time-to-repair.

SPACE NUCLEAR POWER TECHNOLOGY AND SYSTEM CONCEPTS

72

Non-Noble Metal Catalysts for Metal-Air or Fuel Cell Cathodes—GINER, Inc., 14 Spring Street, Waltham, MA 02254-9147; 617-899-7270

Dr. S. Sarangapani, Principal Investigator

Dr. Jose Giner, Business Official

DOE Contract No. DE-AC02-87ER80500

Amount: \$50,000

Platinum when used as an electrocatalyst for oxygen reduction in metal-air batteries and fuel cells suffers from the disadvantages of high cost, susceptibility to poisoning, and sintering. Pyrolyzed macrocyclics continue to attract increasing attention as alternate catalysts, although stability problems have not yet been fully addressed. The operating mechanism of these carbon-nitrogen-iron (C-N-Fe) complexes towards oxygen reduction is far from understood and promises to be an interesting area of research. It is planned to study novel approaches to obtain N-Fe activated carbon, which will help in understanding the common mechanism of C-N-Fe-activated electrocatalysts and in solving the problem of electrocatalyst life.

Anticipated Results/Potential Commercial Applications as described by the awardee: It is expected that the program will lead to the development of a non-noble metal oxygen catalyst for metal-air batteries and fuel cells. These catalysts also may have a potential application in acid fuel cells.

73

High Energy Density Composite Flywheels for Space-Based Energy Storage Systems—Materials Sciences Corporation, Gwynedd Plaza II, Bethlehem Pike, Spring House, PA 19477; 215-542-8400

Mr. Jonathan C. Goering, Principal Investigator

Dr. B. Walter Rosen, Business Official

DOE Contract No. DE-AC01-87ER80481

Amount: \$48,685

A technical research program directed towards the study of high energy density flywheels is planned. A new flywheel concept that incorporates features of both disk and rim storage flywheels will be investigated. This concept uses a number of concentric but separate composite rings as the primary

energy storage device. These rings are sandwiched between two tapered composite disks that provide the mechanism for transmitting energy from the rings to a shaft. Steady-state and dynamic analyses of the flywheel will be performed to determine the strain requirements for the matrix material used in the disks. Candidate materials that exhibit high strain to failure will be studied experimentally. Based on these results, materials will be chosen for prototype development in Phase II.

Anticipated Results/Potential Commercial Applications as described by the awardee: It is anticipated that this research program will lead to the development of a high energy density flywheel concept that may be used in applications that require the quick release of a large amount of energy. By maximizing the energy density of this flywheel, it may be used in areas such as space-based applications where low weight is a premium.

74

Using Porous Metals for Vapor-Liquid Separation in Liquid Metal Rankine Cycle Space Power Systems—PAI Corporation, P.O. Box 1135, Oak Ridge, TN 37931; 615-483-0666

Mr. Robert E. MacPherson, Jr., Principal Investigator
Dr. Doan L. Phung, Business Official
DOE Contract No. DE-AC05-87ER80517
Amount: \$50,000

Separating liquid droplets from the boiler output to provide a high-quality vapor stream for the turbine of a Rankine cycle power system is difficult in space because of gravity, size, and weight considerations. Entrained liquid droplets cause rapid erosion of the turbine blades and reduce the system's reliability. A porous metal barrier is used as a vapor-liquid

separator. The basic concept is that the liquid impinging on a porous metal surface can flow through it to a lower pressure regime whereas vapor flow is restricted because of capillary forces. When the lower pressure side of the porous surface is coupled to a jet pump, so designed that it can recirculate the liquid flow, then a compact and reliable vapor-liquid separator having no moving parts is available to the Rankine cycle space power source. Phase I of this research is devoted to examining specific design concepts using a variety of porous materials, geometries, and working fluids. Both the direct-cycle potassium-cooled reactor system and the lithium-potassium reactor system will be examined. The porous barrier location may be at various locations or combinations thereof, including the boiler outlet, piping sections, or specific locations in the turbine. Experimental data from gaseous diffusion barrier technology and from low-gravity (aircraft flight) tests of the medium power reactor experiment (MPRE) will be used. Viable materials and geometries will be assembled and tested during Phase II using water-steam mixtures. Arrangements will be made with the Oak Ridge National Laboratory to test some liquid metal systems in existing facilities. These Phase II tests shall include those systems deemed viable for space applications and those considered commercially attractive.

Anticipated Results/Potential Commercial Applications as described by the awardee: Theoretical and empirical proof that a porous metal barrier can be used to separate liquid from the vapor-liquid output of a Rankine cycle space power system will be provided. Feasibility of this concept can lead to longer lived, more reliable, and less expensive space power systems. It may also have applications in ground based large steam turbines and in detection devices such as quality meters for liquid metal systems.

FUEL CYCLE TECHNOLOGY

75

Continuous Casting of Metallic Nuclear Fuel without Containment Contact—Creare, Inc., P.O. Box 71, Etna Road, Hanover, NH 03755; 603-643-3800
Dr. Herbert Sixsmith, Principal Investigator
Dr. James A. Block, Business Official
DOE Contract No. DE-AC01-87ER80443
Amount: \$49,658

The Integral Fast Reactor concept has the potential

to provide substantial improvements in the safety and efficiency of nuclear power production. Metallic nuclear fuel in the shape of long, thin rods is the fuel used by the Integral Fast Reactor. The metallic nuclear fuel rods are presently fabricated in a batch-casting process that utilizes quartz tubes of precise dimensions as molds. In this process, molten fuel is injected into the quartz tubes and allowed to cool and solidify. The quartz tubes are then broken to remove the fuel rods. The batch-casting process described

above has several undesirable features that, though problematic for laboratory-scale operations, may prove untenable for large-scale production. First, the precision quartz molds are destroyed after first use and are therefore not cost efficient. Also, the quartz becomes slightly radioactive during solidification; the broken molds therefore constitute radiative waste, which must be safely stored or reprocessed. Further, bits of nuclear fuel may be lost when breaking the mold, making it extremely difficult to account precisely for the whereabouts of all of the nuclear fuel. Finally, the mold may contaminate the fuel by diffusion, especially while the fuel is in the liquid state. In this project it is planned to assess, and then develop if feasible, a continuous casting process that can mitigate or eliminate the undesirable features of the present batch-molding method of forming metallic nuclear fuel rods. Continuous casting, used commonly for structural metals such as steel, eliminates the need for molds, associated radioactive waste, and the potential for loss of solidified material during mold breaking. The novel aspect of the new process involves acoustically levitating the molten fuel in its container on a squeeze-film gas layer. In this way, the molten fuel does not contact its container, and the potential for chemical contamination of the molten fuel is eliminated.

Anticipated Results/Potential Commercial Applications as described by the awardee: If the squeeze-film levitation process proves feasible, the result of this development will be the capability to continuously cast metallic nuclear fuel efficiently in a controlled environment without contamination of the molten metal fuel or production of radioactive waste. This method may also find applications for solidification of single-crystal semiconductors, especially for processes where the crucible contaminates the molten semiconductor.

76

Advanced Heat Pipes for AVLIS Collector Plate Cooling—Thermacore, Inc., 780 Eden Road, Lancaster, PA 17601; 717-569-6551

Mr. Jerome E. Toth, Principal Investigator

Mr. Donald M. Ernst, Business Official

DOE Contract No. DE-AC01-87ER80485

Amount: \$49,803

The use of heat pipes can greatly simplify the difficult problem of cooling the product collector plates in the Atomic Vapor Laser Isotope Separation (AVLIS) technique. Because of very tight space requirements, the cooling technique used must provide sufficient capability to extract the necessary heat and still be compact so as to not interfere with the isotope vaporizing beam train. The heat pipe can effectively satisfy these requirements. This project contains an overall program to develop advanced heat pipes for cooling the AVLIS product collector plates. The advanced design will eliminate the product plates currently used. The uranium vapor will condense directly on the heat pipe evaporator shell, eliminating the thermal interface between these two components and thereby improving the system performance. Phase I of this program will concentrate on the development of the advanced heat pipe design as well as an evaluation and demonstration of the required materials technology necessary to support the concept.

Anticipated Results/Potential Commercial Applications as described by the awardee: The development of advanced heat pipes will offer a solution to the AVLIS collector plate cooling problem. Heat pipes, because of the high thermal conductance and temperature uniformity, will greatly simplify temperature stabilization challenges for the AVLIS designers.

ADVANCED TECHNOLOGIES FOR DECONTAMINATION AND DECOMMISSIONING OF NUCLEAR FACILITIES

77

Ultrasonic Grinding of Zeolites for Radioactive Water Treatment—Energy and Minerals Research Company, P.O. Box 389, Exton, PA 19341; 215-647-7715

Dr. Jeffrey Solash, Principal Investigator

Mr. Ben A. Valocchi, Business Official

DOE Contract No. DE-AC01-87ER80483

Amount: \$49,860

Ion exchange has proven useful for decontamination of radioactive waste waters. Zeolites are now used for this task. Zeolites show several advantages over other ion exchange materials. Ion exchange rates and capacity of zeolites are high. Zeolites are also easily handled. However, optimum size of zeolites for ion exchange is approximately 10-50 mesh. The hot zeolite must be converted to a glass-like brick; 10-50 mesh zeolite does not melt evenly to form a suitable solidified mass. The hot zeolite must be ground to

fine sizes. Prototype ultrasonic grinders have been developed. Most of the development work has been performed using coal. The principle of operation is to cause the coal particles to vibrate ultrasonically. Fatigue crack growth occurs along grain boundaries and discontinuities within several hundred cycles. Remarkably narrow particle size distributions have been observed with coals at modest power inputs. The current prototype configuration, a 4-in. resonant tube-auger, is capable of grinding water-slurried coal at a rate of about 130 kg/hr. A single sample of zeolite has also been ground, and comminuted product of 10-30 μm has been observed. It is planned to examine the grinding variables that control zeolite comminution. The prototype grinders have variable gaps, and the gap size required to produce optimized ground zeolite will be determined as will the optimized grinding rate to produce properly comminuted zeolite. The latter data will be used to size a grinder to grind hot zeolite at a rate of not less than 20 kg/hr. Design work will be started on feed, collection, and operating controls for use in a hot cell. Remote-operating features will be used whenever possible. The new grinder will be designed so that all parts have no single dimension larger than 0.6 m.

Anticipated Results/Potential Commercial Applications as described by the awardee: It is anticipated that a successful Phase I effort will lead to the development of a prototype grinder. The grinder will be capable of comminuting zeolites to 50- μm size range during remote operation. The grinder will be capable of processing at least 20 kg/hr zeolites in water slurry. Successful Phase II effort will result in the enhanced ability of the nuclear industry to decontaminate reactors. Better control of radioactive wastes could lead to increased use of nuclear power. Commercial partners will be sought to further develop the Phase II prototype grinding system into a commercial system. The developed system will be supplied to the nuclear industry.

78

Advanced Abrasive-Waterjet Techniques for the Decontamination and Decommissioning of Nuclear Facilities—Flow Research Company, 21414 68th Avenue South, Kent, WA 98032; 206-872-8500
Mr. Douglas C. Echert, Principal Investigator
Mr. Michael J. Kirby, Business Official
DOE Contract No. DE-AC03-87ER80545
Amount: \$49,514

This program will investigate advanced abrasive waterjet (AWJ) techniques to facilitate the decontamination and decommissioning of nuclear facilities.

Two specific needs are to be addressed: metal surface removal for complete decontamination of large, heavily contaminated metal structures and underwater cutting of thick metals and concrete. An AWJ is a small diameter ultra-high velocity waterjet into which abrasive particles are entrained. Water pressures up to 60,000 psi are used to accelerate the particles. The AWJ technique is in daily use in many industrial applications. It has significant potential for adaption to meet these nuclear industry needs and is especially adaptable to remote and robotic operations. The program will first define the metal surface removal and underwater cutting needs of the nuclear industry. Parametric tests with emphasis on optimization for system performance will be conducted for both applications. The data generated by the program will be combined with existing information to develop conceptual system designs. Ease of use, dependability, and spoils containment and removal will be emphasized in the design effort. An economic analysis of the systems will be done. It will compare the systems with existing techniques in the areas of expected performance, cost of operation, and cost of spoils disposal.

Anticipated Results/Potential Commercial Applications as described by the awardee: Two advanced tools will be developed for the nuclear industry to facilitate decontamination and decommissioning operations in the areas of metal surface removal and underwater cutting. These tools have the potential to reduce significantly the cost of decommissioning operations; the underwater cutting technology also will have application to the offshore industry and to the military; and the metal surface removal technology will have application to machining of exotic metals and advanced composite materials.

79

Percussive Jet Cutting—Scientific Associates, Inc., 1639 12th Street, Santa Monica, CA 90404; 213-450-1334
Dr. Eugene B. Nebeker, Principal Investigator
Dr. Eugene B. Nebeker, Business Official
DOE Contract No. DE-AC03-87ER80528
Amount: \$49,958

The percussive jet is planned as a more rapid and energy efficient means of cutting reinforced concrete and steel than lasers, abrasive blasting, or abrasive jetting. The impact characteristics of percussive jets (initial impacts, tensile failure, and persistence) allow targets to be cut in ways never before attempted. For instance, at 30,000-psig discharge pressure, calculations show the possibility of striking target material

with impulses greater than the ultimate strength of high-strength steel, over 10,000 times per second. Percussive jets apply force to rock as a sequence of high-frequency, short-duration impacts, rather than steadily. These jets can be produced with a conventional, continuous-flow system by modulating the discharge, that is, cycling the discharge rate by a small amount above and below its average. With modulated discharge, the faster part of each cycle overtakes the slower in the free stream. If this process is done properly, the stream becomes bunched instead of uniform and a percussive jet is produced. Previous research with percussive jets has been summarized. Areas in which the technical feasibility needs to be demonstrated are identified and used for a source of Phase I work. In this way, the feasibility

of all items necessary to form a good foundation for the Phase II effort will be proven. Data will be obtained to indicate the operating conditions necessary to accomplish Phase II objectives.

Anticipated Results/Potential Commercial Applications as described by the awardee: If this project is successful to its full potential, a real breakthrough in cutting technology will be realized. Commercial and Federal Government applications will include industrial cleaning and paint removal, highway grooving and bridge removal, hardrock as well as other mining applications, missile silo egress, concrete and metal cutting, and decommissioning nuclear facilities.

COMPUTER APPLICATIONS TO NUCLEAR POWERPLANTS

80

An Expert System Operator Aid for Nuclear Power Plant Maneuvers—Applied Research Associates, Inc., 6404 Falls of Neuse Road, Suite 200, Raleigh, NC 27615; 919-876-0018

Dr. Abdelfatah M. Yacout, Principal Investigator
Dr. Lawrence A. Twisdale, Jr., Business Official
DOE Contract No. DE-AC05-87ER80511
Amount: \$49,959

The safe, reliable, and efficient operation of nuclear powerplants requires advanced operator decision aids as well as control and protection systems. A predictive expert system for planning power maneuvers will be investigated as one such operator aid. In the Phase I work the feasibility of the system will be demonstrated via a robust neutronics model, using the transient few-group neutron diffusion equations. The model will operate in a predictive mode and will be designed to benefit, in later studies, from recent advances in micro-and minicomputer-based parallel architectures. The input plant sensor signals to the model will be simulated by an existing code named NATO. The expert technical specification system will combine observations, experience, insight, rules of good practice, plausible reasoning, and knowledge of widely accepted procedures and methods. Experience will be obtained from interviewing reactor operators, reactor operating training personnel, and consultants. Two maneuvers will be used to demonstrate

the model: (1) recovery to full power from a reactor trip at full power and (2) power reduction from full power at a constant rate, operation at reduced power for a given time, and return to full power within a specified time period. The neutronics model will be constructed so as to be enhanced and integrated easily with a thermal/hydraulics model in Phase II. Both models will then be implemented on a host mini/multiprocessor computer to achieve real-time performance. Plant sensor signals will be obtained from a PWR (Pressurized Water Reactor) simulation loop that is currently under independent development and, if possible, on a reactor training simulator. In Phase II the integrated expert system will be implemented in the OPS5 (official production system, version 5) framework.

Anticipated Results/Potential Commercial Applications as described by the awardee: In Phase I the neutronics model will be completed, plant sensor data simulated using NATO, and the knowledge to be embedded in the predictive expert system will be identified and formalized. The feasibility of the concept will be demonstrated and applied to nuclear powerplant maneuvers. The concept of a computerized operator aid has potential applications in the safe and efficient operation of nuclear reactors as well as in operator training. Substantial savings in replacement energy costs are possible because of fewer lost capacity days.

An Expert System-Based Decision Aid for Reactor Trip Reduction and Post-Trip Analysis—Expert-EASE Systems, Inc., 1301 Shoreway Road Belmont, CA 94002; 415-593-3200

Mr. Joseph M. Holzer, Principal Investigator

Mr. Bjorn Frogner, Business Official

DOE Contract No. DE-AC03-87ER80536

Amount: \$49,996

This project will focus on improving nuclear power plant availability by employing an Expert System-Based Operator Decision Aid to provide guidance to the operation and maintenance of the plant so that both the individual components and the plant remain in the regime of safe operation to minimize inadvertent trips. The primary focus is to develop a system that is both living and learning; that is, it must be easily upgradable and must allow for a testing process that will enable learning. The system will have both the capacity to provide trip avoidance information and postmortem evaluation using an identical knowledge base, thereby providing a strong and active feedback mechanism to enable the growth of the system. The Logic Flowgraph Method, created in an object-oriented environment, will perform the knowledge representation function of the physical system. The logic employed in the reasoning process will be function dependent, either trip avoidance, scenario evaluation, or trip diagnostic, and will utilize some combination of deductive, inductive, abductive, evidential, and model-based reasoning. In total, the capabilities implicit in the envisioned system should be of major benefit to plant operations.

Anticipated Results/Potential Commercial Applications as described by the awardee: It is intended to prove the feasibility and worth of the system in Phase I and to develop a comprehensive prototype in Phase II. The ultimate Decision Aid System should be operable on a 32-bit workstation computer such as a SUN, APOLLO, MICROVAX II, or TEKTRONIX, which should be very cost competitive when the research and development is completed. There will be two sets of users: The primary set consists of nuclear powerplant owner/operators. The secondary set might be any process system characterized as having shutdown trips and economic loss from lost system availability.

Signal Validation by Combining Model-Based and Evidential Reasoning Approaches—Expert-EASE Systems, Inc., 1301 Shoreway Road, Belmont, CA 94002; 415-593-3200

Dr. Bjorn Frogner, Principal Investigator

Dr. Bjorn Frogner, Business Official

DOE Contract No. DE-AC03-87ER80539

Amount: \$49,950

This project will merge methods derived from Artificial Intelligence technology with conventional analytic redundancy methods, the objective being to obtain in real-time highly sensitive and cost-effective identification of degradation in powerplant instrumentation. The research will start with the experience that is available in the use of simulation models and observers/filters to estimate unmeasured states. Statistical analysis of the residual difference between measured and predicted values will be used to identify anomalies. The weak link in the application of these methods in the past has been the codification of the experience needed to interpret the results accurately and automatically. The use of evidential reasoning embedded into an expert system will be investigated in this project to facilitate the implementation of such heuristics.

Anticipated Results/Potential Commercial Applications as described by the awardee: The end product will be a programmable signal validation capability for distributed sub-loops similar to programmable controllers. The market potential for such a product is expected to be of the same order of magnitude as the market for microprocessor-based controllers.

Enhanced Distributed Recovery Blocks for Nuclear Reactor Control and Safety Functions—SoHar, Inc., 8500 Wilshire Blvd., Suite 1027, Beverly Hills, CA 90211; 213-935-7039

Dr. Herbert Hecht, Principal Investigator

Dr. Herbert Hecht, Business Official

DOE Contract No. DE-AC03-87ER80532

Amount: \$49,969

Despite the pressing need, there is currently no widely accepted and licensed digital system for replacement of aging analog reactor safety and protection hardware. The primary obstacle has been the lack of a credible implementation of software fault tolerance supported by an appropriate system architecture. This research will develop and test an innovative construct in software fault tolerance called Enhanced Distributed Recovery Block (EDRB) as a means of overcoming this obstacle. EDRB is designed for a network of microcomputers controlling highly critical functions such as the Safety Actuation System of a PWR (Pressurized Water Reactor). This network architecture allows the system to be implemented as an ensemble of relatively simple and testable

functional subunits that are isolated from each other both physically and logically. The isolation largely eliminates unanticipated interactions and makes the design much easier to verify, analyze, and certify than the centralized architectures currently used by several reactor vendors. EDRB is a very broad, software-implemented, fault-tolerant mechanism for such a network. Through EDRB computers detect failures in other units and effect a recovery on the application software, system software, or hardware level.

Anticipated Results/Potential Commercial Applications as described by the awardee: The anticipated result is a fault-tolerant digital reactor control or safety system consisting of a network of microcomputers each of which controls a well-defined partition of sensors, actuators, and alarms. Broad and verifiable fault tolerance at the node level is ensured through EDRB. By virtue of its modular and distributed structure, the system is maintainable and extensible. Each module is a certified function linked to the system through standard interfaces that include fault tolerance provisions such as data checking, timeouts, and flow control.

84

The Design of a Reliable Fuzzy Fault-Tolerant Automatic Control—Technology International, Inc., 429 West Airline, Suite S, LaPlace, LA 70068;

504-652-1127

Mr. Rodrigo Rodriguez, Principal Investigator
Dr. A. A. Husseiny, Business Official
DOE Contract No. DE-AC05-87ER80509
Amount: \$49,970

The application of fuzzy set theory to automatic control has been shown to affect high-quality reliable controls in applications pertinent to nuclear power plant equipment. A scheme is developed here based on incorporation of software-tolerant methods to ensure high reliability of software. Applications of the method to centrifugal pumps and heat exchangers will be selected to demonstrate the viability of a redundant technique using fuzzy and deterministic controls. The work is aimed at development of a methodology to ensure reliability of control systems when they interact or become part of the plant protection system. This is a step towards providing autonomy in controlling complex processes such as nuclear reactors.

Anticipated Results/Potential Commercial Applications as described by the awardee: The development of the methodology will accelerate the effective applications of automation and digital processing control systems in nuclear powerplants and nuclear reactors used in space, research, and in unattended remote locations. The development will benefit the Federal Government through increase in safety levels and the industry in minimizing the burden of human training.

COAL UTILIZATION AND CONVERSION

85

Copper Based Sorbents for Hot Gas Cleanup—ElectroChem, Inc., 400 West Cummings Park, Woburn, MA 01801; 617-932-3383
Dr. Vinod Jalan, Principal Investigator
Dr. Vinod Jalan, Business Official
DOE Contract No. DE-AC02-87ER80494
Amount: \$49,688

Over the past decade there has been a continuing effort by DOE/METC (Morgantown Energy Technology Center) and its contractors to define an appropriate high temperature regenerable desulfurizing agent. Successful sorbents should provide efficient desulfurization and regeneration kinetics, a reduction of H_2S concentrations to 1 ppm or less, and physical and chemical stability in both desulfurization and regeneration gas atmospheres at temperatures of

500°C and above. It is planned to investigate copper- and manganese-based mixed oxides (Cu_2O and MnO)—an innovative integration of two technologies that were examined individually and abandoned. Copper by itself is not attractive for low level sulfur removal but can be stabilized to cuprous oxide in the presence of other oxides. The MnO system shows an unprecedentedly high level of scrubbing capacity and regeneration efficiency but moderate scrub efficiency. The inclusion of Cu_2O in MnO should provide the appropriate sorbent characteristics. The chemical feasibility of such a system will be established. This will include the demonstration of very low level sulfur content in the effluent stream, high sulfur uptake capacity, and regenerability. In Phase II bench-scale evaluation will be addressed for structural and mechanical stability to survive a protracted series of high temperature sulfidation/regeneration duty cycles in fixed as well moving or fluidized bed reactors.

Such testing would critically consider certain operation parameters, such as gas composition, temperature, pressure, presence of organic sulfur and other trace contaminants.

Anticipated Results/Potential Commercial Applications as described by the awardee: The fact that DOE has searched for a decade for an appropriate hot gas cleanup sorbent is testament to the importance of such a material. Conventional gas cleanup systems can cost as much as 25% of the cost of a coal gasifier-based powerplant. This cost limits the use of coal in the United States. A successful program should enhance national coal use.

86

Operation of Phosphoric Acid Fuel Cells on Coal Gases—ElectroChem, Inc. 400 West Cummings Park, Woburn, MA 01801; 617-932-3383
Dr. Vinod Jalan, Principal Investigator
Dr. Vinod Jalan, Business Official
DOE Contract No. DE-AC02-87ER80493
Amount: \$49,707

The objective of this project is to develop improved anode electrocatalysts for coal gas based phosphoric acid fuel cells (PAFCs). Because of the presence of carbon monoxide (CO) and hydrogen sulfide (H_2S) in coal-derived gases, the reversibility of hydrogen oxidation on platinum in phosphoric acid is adversely affected, and polarization losses at the anode are much higher than could be expected from the behavior of pure hydrogen at the anode. The utilization of energy in coal gas fueled PAFC can be increased significantly through the development of improved anode electrocatalysts, which are resistant to poisoning by CO and H_2S simultaneously. Primary emphasis in this program will be to prepare platinum and platinum alloy electrocatalysts with high surface area and to obtain improved catalyst utilization. Novel platinum alloys in a highly dispersed form will be prepared using state-of-the-art technology and will be compared with known electrocatalysts for activity and stability for coal gas fueled PAFC.

Anticipated Results/Potential Commercial Applications as described by the awardee: During Phase I advanced electrocatalysts with substantial resistance to poisoning by CO and H_2S will be identified. Subsequent development of CO- and H_2S -tolerant anode electrocatalysts would contribute to the commercialization of coal gas fueled PAFC powerplants. Furthermore, the successful incorporation of such catalysts into fuel cells would drastically reduce the

secondary fuel-processing requirements in natural gas or naphtha-fueled PAFCs. As an extreme case, a simple thermal cracking of methanol could be utilized for transportation applications and make the use of undiluted methanol a reality for military applications.

87

Coal Conversion in Low Temperature Molten Salts—Energy and Minerals Research Company, P.O. Box 389, Exton, PA 19341; 215-647-7715
Dr. Jeffrey Solash, Principal Investigator
Mr. Ben A. Valocchi, Business Official
DOE Contract No. DE-AC01-87ER80482
Amount: \$49,761

Low temperature molten salts based on Al, Fe, and B are known. Recently, unique organic chemistry has been demonstrated in these eutectic mixtures. These low temperature eutectics ($\sim 100^\circ C$) are attractive media for coal conversion. The eutectics should dissolve large quantities of hydrogen. By controlling the acidity of the mixtures, coal cleavage reactions should be enhanced. Ether cleavage reactions should be vastly accelerated by specific chelation in these molten salts. It has already been demonstrated that oil shale can be converted to liquids at temperatures several hundred degrees centigrade lower than in thermal processes. This project will examine coal conversion to toluene solubles in sodium tetrachloroaluminate, ferric chloride-sodium chloride, and boron tribromide based melts. Melt temperatures from near eutectic point to $250^\circ C$ will be examined. The effect of modest hydrogen pressure (50, 200, 500 psig at temperature) also will be examined. Where conversion is high, the effect of dissolved water will be examined. A brief study of model compound reactions will be performed, if warranted. Finally, a comparison of molten salt conversion results with conventional direct liquefaction results will be made.

Anticipated Results/Potential Commercial Applications as described by the awardee: If Phase I is successful, the improved conversion of coal to distillates in low temperature molten salts will be demonstrated. It is anticipated that the molten salt medium will promote the conversion of coal at very low temperatures and hydrogen pressures. In Phase II, the continuous conversion of coal on a small bench-scale unit (lb/hr capacity) will be demonstrated. Conversion rates, product quality, and operability problems will be determined. Phase II results should allow an assessment of the commercial potential of this coal conversion approach.

A Novel, Moderate Temperature Fuel Cell—GINER, Inc., 14 Spring Street, Waltham, MA 02254-9147; 617-899-7270

Dr. John A. Kosek, Principal Investigator

Dr. Jose Giner, Business Official

DOE Contract No. DE-AC02-87ER80444

Amount: \$50,000

As evidenced by all ongoing development efforts, there is little doubt that a market exists for a fuel cell capable of rejecting carbon dioxide, but not suffering from the serious materials problems shown by phosphoric acid and higher temperature fuel cells, and achieving this goal at equal or higher cell efficiency than the phosphoric acid fuel cell and at no added capital cost. It is planned to determine the feasibility of developing a novel, moderate temperature fuel cell; this system is based on proprietary techniques. During Phase I experiments will be run on a fuel cell under a number of operating conditions, and a system analysis will be performed to investigate the commercial feasibility of the complete system.

Anticipated Results/Potential Commercial Applications as described by the awardee: It is expected that this fuel cell will use electrocatalysts other than noble metals and inexpensive construction materials. This fuel cell will be operated under temperature and pressure conditions similar to those used in the phosphoric acid fuel cell and has a potential for long life. This system would have commercial application in some areas of electric traction as well as in the utility sector.

A Low Pressure Drop Gas Phase Alkali Metal Scavenger—KSE, Inc., P.O. Box 368, Amherst, MA 01004; 413-549-5506

Dr. J. R. Kittrell, Principal Investigator

Dr. J. R. Kittrell, Business Official

DOE Contract No. DE-AC02-87ER80497

Amount: \$49,912

Integrated coal gasification combined cycle power generation is an environmentally sound and flexible technology that could provide an economically attractive outlet for the vast coal resources of the United States. To capture fully the potential, treatment of the synthesis gas to remove objectionable elements in a hot, high pressure stream is essential. Volatile trace alkali metals have been found in raw gases produced by coal gasification. The use of in-bed desulfurization increases the potential for alkali

metal contamination of the raw gas. These metals are a source of corrosion in the gas turbines of a combined cycle plant as well as a potential environmental concern. Alumina is a known absorbent for alkali metals. A parallel passage reactor fabricated from screens impregnated with alumina will be tested as a low pressure drop gas phase alkali metal scavenger. This technology appears to offer a low cost approach to removal of alkali metals from hot gas streams.

Anticipated Results/Potential Commercial Applications as described by the awardee: The results of this project should provide a preliminary proof of concept and economic analysis for removing alkali metals from hot raw gases using a low pressure drop parallel passage reactor system fabricated from an alumina-impregnated screen. A key potential commercial application is protection of turbine materials for IGCC (integrated coal gasification combined cycle) technology using hot gas cleanup. Other applications include protection of hot-side catalysts (e.g., shift, hydrolysis) used in coal gasification, lead removal from smelter gases, and metal removal in refuse incineration.

Monitoring Erosion in Coal Combustion Engines Using Surface Layer Activation—Spire Corporation, Patriots Park, Bedford, MA 01730; 617-275-6000
Dr. Charles C. Blatchley, Principal Investigator
Mr. Richard Gregorio, Business Official
DOE Contract No. DE-AC02-87ER80492
Amount: \$49,830

A prototype automated system has been developed for precise in situ measurement of wear, corrosion, or erosion based on the surface layer activation (SLA) technique. Measurements are made by detecting the gamma ray signals from trace amounts of radio-nuclides incorporated in the surface of the wearing parts. Amounts are so small that safety and disposal are not problems. The nuclides are produced by short, controlled exposure to particles from a Van de Graaff or cyclotron accelerator and serve as surface markers (as opposed to tracers) for measurement by an externally located detector system. The measured decrease in activity is directly correlated with loss of surface material by calibration measurements, allowing an extremely precise, often submicrometer determination of wear. This method has been used successfully to measure micrometer-scale wear from diesel engine cylinder liners, piston rings, bearings, cam shafts, and other reciprocating gasoline engine components. This research program will investigate the feasibility of adapting the SLA approach to measuring the relatively high wear rates plaguing

both turbine and reciprocating engines operating with coal-based fuel. The anticipated extreme precision of the technique should allow the assessment of previously undetectable dynamics in wear rates or differences in durability of test materials. On-line capability will enable detailed monitoring of wear as a function of operating condition or fuel composition. Because of the severity of the erosion problem in systems using coal slurries or micronized coal as fuel, a precision on-line wear-monitoring approach will be critical in evaluating and improving the effectiveness of measures taken to counter wear.

Anticipated Results/Potential Commercial Applications as described by the awardee: This approach will allow a rapid evaluation of the effectiveness of modified operating conditions, system designs, or fuel compositions on the wear rate without requiring dismantling or even stopping of the engine. The high precision involved will allow short tests, which reduce operating expenses and minimize wear damage. The system can therefore be used to test several configurations or fuels without replacement of damaged parts.

91

Application of RAPRENO_x to Reduce Nitrogen Oxides from Coal Fired Combustors—Technor, Inc.,
524 Hazel Street, Livermore, CA 94550;
415-443-5078

Dr. Robert A. Perry, Principal Investigator

Dr. Robert A. Perry, Business Official
DOE Contract No. DE-AC03-87ER80530
Amount: \$49,997

Coal contributes 30% of the nitrogen oxide emissions in the United States. These emissions result in photochemical air pollution and acid rain. It is estimated that by the year 2000, nitrogen oxides will surpass sulfur dioxide as the major source of acid rain. Thus, a national need exists to reduce nitrogen oxides in coal combustor exhaust gases. At Sandia National Laboratory, a process referred to as RAPRENO_x (RAPid REduction of Nitrogen Oxide), has successfully reduced nitrogen oxides from diesel exhaust. It is planned to investigate the application of this process for use in removing nitrogen oxide from the exhaust gases of coal-fired combustors. Possible injection techniques, the effects of sulfur dioxide, and temperature will be assessed in Phase I. These results will lead into Phase II where a prototype for a commercial device will be designed and tested.

Anticipated Results/Potential Commercial Applications as described by the awardee: The planned research should result in the commercialization of a new process to remove nitrogen oxides from exhaust gases. The technology offers the possibility of reducing more than 99% of the nitrogen oxides from both large-scale utility boilers and small-scale applications, such as pumping stations and residential furnaces, which together significantly contribute to nitrogen oxide emissions.

FOSSIL ENERGY INSTRUMENTATION

92

A Catalytic Combustion Gas Energy Meter—Hart Scientific, Inc., 177 West 300 South, Provo, UT 84601; 801-375-7221

Mr. Roger M. Hart, Principal Investigator

Mr. Dennis R. Hunter, Business Official

DOE Contract No. DE-AC03-87ER80546

Amount: \$50,000

A catalytic combustion flow calorimeter for the measurement of natural gas energy content will be developed and tested. This new calorimeter (gas energy meter) will be designed to be a prototype for development of an instrument suitable for remote installation, as accurate as present laboratory calorimeters, operable continuously for precise accounting at custody transfer points, and low in cost. Presently

there are no existing instruments capable of making real-time and continuous Btu measurements in a hostile environment at remote sites. This project addresses a very real and significant problem for the gas industry and all consumers of natural gas. The need for a low cost field-deployable gas energy meter has developed from the shift of gas billing from a volume to an energy basis and more recently by the Federal Energy Regulatory Commission's ruling that gas pipelines should be regulated as common carriers. The program objective is to produce a laboratory prototype instrument that will demonstrate the advantages of the energy meter design. To accomplish this objective the following five tasks will be completed: (1) develop a catalytic combustion reactor, (2) design a gas calorimeter flow cell employing the catalytic reactor, (3) design a microprocessor control and data collection system for the calorimeter,

(4) test the complete gas calorimeter system and develop appropriate operating and maintenance procedures, and (5) construct a prototype gas calorimeter for testing.

Anticipated Results/Potential Commercial Applications as described by the awardee: The potential commercial applications of the innovation are far reaching and include energy management and control, petroleum refining, synfuels and chemical processing, and the natural gas, steel, and metal production industries.

93

An Infrared Diode Laser Spectrometer with Enhanced Sensitivity for Combustion Research—Southwest Sciences, Inc., 1570 Pacheco Street, Suite E-11, Santa Fe, NM 87501; 505-984-1322

Dr. Joel A. Silver, Principal Investigator

Dr. Alan C. Stanton, Business Official

DOE Contract No. DE-AC03-87ER80541

Amount: \$49,976

The development of nonintrusive sensors to measure combustion species concentrations in high temperature, particle-laden environments is important in kinetic rate studies, in following the evolution of reactant species in laboratory-scale combustors, in studying corrosion processes, and in monitoring critical species in full scale systems for controlling emissions or for optimizing combustion efficiency.

Instrumentation based on tunable diode laser absorption spectroscopy has wide generality for detecting many combustion species. To date, however, such systems have usually been bulky and awkward to operate and do not have adequate sensitivity for the measurement of a number of important species that exist in combustion environments at low concentrations. The development of a rapid response (faster than 0.1 second), high sensitivity sensor using single-mode, liquid nitrogen-cooled, lead-salt diode lasers is planned. The major objective of the Phase I effort is to use such instruments to extend the sensitivity of diode laser absorption measurements beyond presently attained levels. In particular, high frequency optical heterodyne techniques will be studied that should permit determination of noise-limited performance during the laser burst. Results of the Phase I study will provide the required design information for the Phase II development and testing of a high sensitivity, compact instrument with wide application for measurement of trace combustion species.

Anticipated Results/Potential Commercial Applications as described by the awardee: The development of a highly sensitive, compact, fast response monitor for critical gas phase combustion species has potential commercial applications in laboratory research instrumentation, emissions monitoring, combustor control and optimization, and toxic gas sensing, as well as a wide range of industrial processes where real-time monitoring of low concentration gases is required.

ENHANCED OIL RECOVERY AND TAR SANDS

94

A Novel, Insulated, Double-Walled Tube Design for Thermally Enhanced Oil Recovery—Carbotek, Inc., 2916 West T.C. Jester, Suite 101, Houston, TX 77018; 713-688-7840

Dr. Christian W. Knudsen, Principal Investigator

Dr. Christian W. Knudsen, Business Official

DOE Contract No. DE-AC02-87ER80447

Amount: \$50,000

A novel, double-walled, vacuum-insulated tube is planned for efficient transmission of hot water or steam for enhanced thermal recovery of heavy oil from deep oil reservoirs. This design improves the structural reliability while providing improved thermal insulation having a low manufacturing

cost. Phase I of this program involves the detailed analysis, design, and optimization of the tubing. A plan will be prepared for the testing necessary to prove feasibility and manufacturing techniques. This test and development plan will then be implemented in Phase II.

Anticipated Results/Potential Commercial Applications as described by the awardee: Successful development of this technology should provide reliable, efficient, economical insulated tubulars for enhanced oil recovery systems using varying amounts of steam or hot water with temperatures up to 700°F. Because of the thin insulating annulus, this concept has potential for insulating both high temperature and cryogenic tubing where space is limited.

High Efficiency Tar Sand Oil Recovery—Energy Recovery Technology, 25W 280 Highview Drive, Naperville, IL 60540; 312-357-5784

Dr. D. Carlos Adams, Principal Investigator

Dr. D. Carlos Adams, Business Official

DOE Contract No. DE-AC02-87ER80490

Amount: \$50,000

The Counter Current Solid Streams Heat Transfer (CCSST) retort is a new process for efficient oil recovery from our plentiful tar sands and oil shale reserves. As a heat recovery soil incinerator, it has the advantages of reduced fuel demand and low combustion gas product (reducing air pollution control needs for the incinerator). The CCSST unit is a single vessel rotating kiln that (1) preheats ore, (2) retorts the ore, (3) generates process heat from the coke combustion, (4) cleans the coke from the sand, (5) recovers the heat from the clean sand, and (6) cools the oil vapor to avoid oil coking. These six functions, all regulated by the kiln and stream flowrates, provide a simple, efficient, and low cost process. Besides producing clean cool ash, the system is also ecologically attractive for use with carbonate ores because it generates less alkaline ash than other processes—the Western U.S. oil shales contain nearly half carbonate minerals. Based on rotary fluidization, the CCSST retort is expected to operate nearly as effectively as gas fluidization. Oil recovery is expected to exceed that of ash recycling systems by more than 20%. It enables high efficiency heat recovery from ash in a new approach that avoids the need of capital intensive boilers and power generators. This Phase I study will (1) construct a batch reactor (2 to 8-lb sample size), which will process an element of ore through the stages of heat-up, retorting, coke combustion, and cool-down, thus simulating the CCSST continuous-process unit; (2) investigate conditions contributing to high oil yield; (3) investigate the performance of the CCSST concept with a variety of ores; and (4) generate heat transfer data for the design of a process development unit. During Phase II the performance of the CCSST continuous-flow retort will be demonstrated in a 1 to 5-ton/day process development unit.

Anticipated Results/Potential Commercial Applications as described by the awardee: The United States currently imports five million bbls oil/day, seriously affecting our balance of payments and subjecting national security to foreign interest. The CCSST process should significantly improve the process economics of bitumen oil recovery and significantly contribute toward our urgent need to make synthetic oil competitive.

Application of Time-Delayed Gels for Fluid Control as an Oil Recovery Displacement Process—

Remington Energy Corporation, 5553 South Peoria

Avenue, Suite 117, Tulsa, OK 74105; 305-665-6184

Mr. Joseph Lawnick, Principal Investigator

Mr. Jon Solow, Business Official

DOE Contract No. DE-AC05-87ER80513

Amount: \$49,318

In many fluid injection processes used for oil recovery, such as waterflooding, the injected fluids flow preferentially through the rock zones of high flow capacity (high permeability), bypassing oil that is present in the tighter parts of the reservoir rock. This may result in high water-to-oil-producing ratios and abandonment of a project at a relatively low volumetric sweep efficiency. One approach to improved sweep efficiency is to place a gelled polymer into the high permeability zones, thereby diverting the injected fluid into tighter parts of the rock. Current technology relies on the injection of gelled or gelling polymer solutions into the high permeability intervals near the wellbore to plug them. The solutions gel within a day or two; thus treatment is confined to the region in the immediate vicinity of the wellbore. The effectiveness of this treatment is often limited by crossflow of the injected fluid between high and low permeability regions. That is, when the treatment is confined to the region near the well the injected fluid may simply flow around the treated region and into the high permeability zone. It is planned to investigate an innovative process that has the potential for in-depth permeability modification, thus reducing the effect of crossflow. This process is based on delaying the gelation of polyacrylamide polymer by generating the crosslinking agent, chromium(III), in situ and controlling the rate of this reaction through chemical kinetics. Previous DOE sponsored research at the University of Kansas has shown that gelation times of days to months can be obtained in the laboratory by appropriated selection of compositions. However, the process has not received sufficient field testing. We will evaluate the feasibility of in-depth permeability modification using a delayed gel system by field testing in an oil reservoir in southeast Kansas. The test reservoir is known to have a water-channeling problem and poor waterflood sweep efficiency. In Phase I the emphasis will be on the gel system design and on the placement of the gel system in the reservoir.

Anticipated Results/Potential Commercial Applications as described by the awardee: If the objectives of the program are met, the technology could be used to increase the volumetric sweep in waterfloods, thus causing the waterflood technique to be more efficient.

This alone would increase the nation's oil reserves by millions of barrels. Another use of the technology might be to increase oil production in reservoirs in which waterconing exists due to a natural water

drive. The gels could be used to reduce the coning. If results are successful, it is planned to establish a small business based on in-depth permeability modification using in situ gelation.

FOSSIL ENERGY MATERIALS

97

Design, Fabrication, and Interface Characterization of Ceramic Fiber-Ceramic Matrix Composites—
Ceramatec, Inc., 2425 South 900 West, Salt Lake City, UT 84119; 801-972-2455
Mr. David W. Richerson, Principal Investigator
Mr. John F. Grennan, Business Official
DOE Contract No. DE-AC05-87ER80463
Amount: \$48,870

Ceramic-matrix composites with optimum fiber-matrix interfacial bonding exhibit high strengths, fracture toughness, and a damage-insensitive failure mode, and they are vastly superior in reliability to monolithic ceramics. The design and fabrication of these composites require innovative techniques to control, modify, and characterize the fiber-matrix bonding. Two novel techniques for measuring the interfacial shear debond strength (τ_d), coefficient of sliding friction at the interface (μ), and the residual interface pressure (σ_i) are planned for a feasibility study in this Phase I of a three-phase research program. The techniques developed in Phase I will be employed to design and tailor interfaces in ceramic composites that will exhibit high strengths, fracture toughness, and the damage-insensitive mode of failure. Production of specific components of the composites for commercial applications will be addressed in Phase III.

Anticipated Results/Potential Commercial Applications as described by the awardee: Ceramic-matrix composites designed to exhibit a flaw-insensitive failure mode are superior in reliability to monolithic ceramics, and they will be used in such applications as heat exchanger tubes, load-bearing components in advanced engines, and a variety of wear parts.

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Coatings for High Temperature Ceramic Filters—
Energy Materials Research Company, 2398 4th Street, Berkeley, CA 94710; 415-644-2244
Mr. John Brookes, Principal Investigator
Mr. John Brookes, Business Official
DOE Contract No. DE-AC05-87ER80505
Amount: \$49,880

Integrated Gasification Combined Cycle (IGCC) approaches to coal gasification require high temperature filters for removal of particulates directly after the primary reaction step. These filters must have high flexure strength during reverse flow cleaning. Ceramic coatings for the filters promise to improve the strength and corrosion resistance of filter fibers. The planned work is to develop high performance ceramic coatings based on flake particles. The flakes adhere to the surface of fibers and sheets to provide mechanical and chemical protection. These ceramic flakes are made in a vacuum-plasma process, using a wide range of materials. Release coatings allow very thin films of ceramics to be collected and separated into bulk particles with a flat aspect ratio. Preliminary studies using microflakes on fiberglass weaves have shown promising results. It is projected that the current coating will extend the temperature and corrosion resistance of ceramic fiber filters by providing a chemical and antifriction layer that is strong and adherent.

Anticipated Results/Potential Commercial Applications as described by the awardee: Potential applications include high temperature corrosion barriers for furnaces, flues, filters, and engines. Because the flakes can have hardness approaching diamond, antiabrasion coatings can be developed. Finally, the tailorability of electrical and optical properties will allow specialty coatings such as conductive inks and transparent conductive coatings that can be applied like a paint.

PHOTOVOLTAIC RESEARCH

99

On-Line Purifiers for Chemical Vapor Deposition—
Advanced Technology Materials, Inc., 520-B Danbury Road, New Milford, CT 06776; 203-355-2681
Dr. Glenn Tom, Principal Investigator
Dr. E. G. Banucci, Business Official
DOE Contract No. DE-AC01-87ER80469
Amount: \$49,916

The materials used in thin-film photovoltaic cells and many other semiconductor devices are frequently grown using chemical vapor deposition (CVD) or other vapor-based processes. Many of the process gases used, for example, arsine, phosphine, ammonia, diborane, and silane, are highly reactive. Contamination, chemical or particulate, of these reactive gases seriously interferes with device performance. Particle contamination can be reduced by filtration, but similar approaches to address chemical contamination are not commonly available. Inert gases such as hydrogen and helium are now routinely purified at the point of use, but the reactive gases used in CVD require more sophisticated purification techniques. By using supported reagents, on-line purifiers can be designed that will remove oxygen, water, and certain other contaminants from the broad spectrum of reactive gases. During Phase I a unifying theory for reducing the contaminants in these gases to parts per billion levels will be tested. A purifier will be built, analytical methods developed, and its purification capability demonstrated. Phase II will incorporate the design and testing of purifiers for each of the reactive process gases and on-line evaluation during actual device fabrication.

Anticipated Results/Potential Commercial Applications as described by the awardee: On-line reactive gas purifiers will reduce defects and enhance

photovoltaic solar device efficiencies by eliminating the most common chemical contaminants found in these gas streams. This technology will also be applicable to semiconductor device fabrication.

100

Optical Optimization of Multijunction Thin Film Silicon Hydrogen Solar Cells—Spectracom, P.O. Box 3178, Simi Valley, CA 93063; 818-341-4087
Ms. Kimberly L. Eskenas, Principal Investigator
Ms. Kimberly L. Eskenas, Business Official
DOE Contract No. DE-AC03-87ER80531
Amount: \$48,000

To achieve the predicted high power conversion efficiencies of multijunction amorphous silicon solar cells (a:Si), efficient use of all incoming solar radiation is necessary. Multijunction solar cell devices are efficient collectors of incident light, in theory, because light with energy less than the bandgap edge of the first junction may be effectively absorbed by the junction below. In practice, significant reflectance losses occur because of optically mismatched layers. An innovative solution to this problem is the use of optically optimized, thin film multilayer front and back contact designs. The objective of the project is to investigate a novel design approach for optically optimized front and back contact configurations for a tandem a:Si solar cell device. The optimized thin film stacks serve to reduce reflection losses as well as to maximize the transmission of incident light to the device below.

Anticipated Results/Potential Commercial Applications as described by the awardee: Commercial applications will be low cost, high efficiency multijunction a:Si alloy solar cells for terrestrial and space power applications.

SOLAR THERMAL TECHNOLOGY

101

A Multibar Rim Drive for Heliostat Solar Concentrators—Dan-Ka Products, Inc., 3862 South Kalamath, Englewood, CO 80110; 303-789-1026
Mr. Daniel V. Sallis, Principal Investigator
Mr. Daniel V. Sallis, Business Official
DOE Contract No. DE-AC02-87ER80488
Amount: \$50,000

Stretched membrane mirror structures are under development as a potential significant improvement for solar concentrator mirrors for heliostats and dishes. The planned multibar rim drive concept is a similar potential improvement for supporting and steering these mirror structures. The drive concept could be incorporated into the present generation of heliostat designs; however, it is expected that it would be more beneficial when used with the stretched membrane structural concept. The primary improvement is that it carries the loads directly from the rim to multiple points on the ground, thus eliminating the need to carry the loads back to a center post. In addition the multibar concept allows the mirror to be stowed in a face-down position, which may prove mandatory to protect the thin membrane reflective surface from hail.

Anticipated Results/Potential Commercial Applications as described by the awardee: Development of the multibar rim drive should result in significant structural weight reduction and corresponding cost savings for stretched membrane heliostat solar collectors. These improvements should contribute to the implementation of membrane heliostats.

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Methods of Reduction of Wind-Induced Dynamic Response in Solar Concentrators and Other Small Lightweight Structures—LaJet Energy Company, 3130 Antilley Road, Abilene, TX 79606; 915-698-8800
Mr. Monte McGlaun, Principal Investigator
Mr. Dean Low, Business Official
DOE Contract No. DE-AC05-87ER80519
Amount: \$50,000

Recent wind tunnel studies on solar concentrator structures indicate that structures with low damping properties are potentially susceptible to the spectral nature of atmospheric wind loading. Solar

concentrators are sensitive to deflections in optical mounting and tracking systems; consequently, structures and drives with sufficient rigidity to resist dynamically induced loading with minimal deflections are costly. The cost and performance characteristics of solar concentrators and other relatively small structures such as power transmission line supports and highway signs can be improved through structural design approaches that reduce dynamic response. Through the use of finite element modeling, Phase I of this study evaluates the cost and functional benefit of various methods to control dynamic response. Among the methods to be considered are passive damping, multiple supports, friction connections, mass alterations, beam length modification, and alternate materials selection.

Anticipated Results/Potential Commercial Applications as described by the awardee: The objective of the study is to develop techniques for the reduction of dynamic responses to wind loading within relatively small structures such as solar concentrators, power transmission line supports, and highway signs. The study will attempt to determine the effectiveness of methods such as passive damping, multiple supports, friction connections, mass alterations, beam length modification, alternate materials selection, and other methods that may be identified in reducing the effects of dynamically induced wind loading. The long-range goal will be to provide documented guidelines for the design of small wind loaded structures to improve performance and reduce cost.

103

Multiphoton Processes Promoted by Concentrated Solar Energy—M. L. Energia, Inc., P.O. Box 1468, Princeton, NJ 08542; 609-799-7970
Dr. Moshe Lavid, Principal Investigator
Dr. Moshe Lavid, Business Official
DOE Contract No. DE-AC01-87ER80479
Amount: \$50,000

Advanced solar collector technology can provide light intensities several thousand times that of incoming sunlight. Achievement of such intensities suggests a novel opportunity: promotion of multiphoton chemical processes by solar sources. At very high light intensities, more than one quantum of radiation can be absorbed by a single molecule. The resultant multiphoton absorption can lead to new photochemical reaction pathways for chemical

synthesis, and to more complete use of the solar spectrum by energy storage reactions. It is intended to study the feasibility of using existing solar collector technology to provide a new radiation source for multiphoton processes, particularly in the gas phase. This will be an experimental study in the laboratory using solar simulators. Several model chemical systems will be subjected to intense near-infrared radiation and analyzed for multiphoton reactivity. Candidate model systems will include up-conversion of saturated hydrocarbons to unsaturates and hydrogen, isomerization of norbornadiene to quadricyclane, and alcohol decomposition. If multiphoton reactivity is achieved, the molecular reaction mechanism will be studied. Based on established photophysical principles, the initial prediction is a tandem mechanism: single-photon excitation of vibrational overtone and combination transitions, followed by multiphoton population of the vibrational quasi-continuum. This will be diagnosed by rapid infrared transmission spectroscopy with tandem laser and infrared sources. Phase II research will utilize actual concentrated solar radiation to investigate commercial opportunities and more thoroughly characterize the phenomenon.

Anticipated Results/Potential Commercial Applications as described by the awardee: It is anticipated that this program will demonstrate that concentrated solar energy is capable of promoting multiphoton processes. This, in turn, will initiate major new applications for existing solar concentrator technology. It holds potential for at least three areas of commercial importance: solar to chemical energy storage, chemical and material synthesis, and enhanced propulsion for high altitude flight vehicles.

104

The Development of Optimum Structural Supports for Large Aperture Stretched Membrane Heliostats—

Solar Kinetics, Inc., 10635 King William Drive, Dallas, TX 75220; 214-556-2376

Mr. David L. White, Principal Investigator

Mr. J. A. Hutchison, Business Official

DOE Contract No. DE-AC05-87ER80518

Amount: \$48,662

A structural support system for large aperture, stretched membrane heliostats will be developed. This support system provides a tracking platform and resistance to the wind load environment. Stretched membrane heliostats enjoy a simplicity and structural efficiency that results in low reflector costs. Membrane technology is particularly suited to capture economies of scale through large aperture concentrators. The major limitation in achieving further reduction in price and increase in size is the support structure. Developed support systems are substantially heavier than the reflector, and may not take full advantage of the unique structural characteristics in membrane concentrators. In Phase I, the relationship between the mirror module, load environment, and material efficiencies will be defined. Alternative support configurations that overcome limitations to large apertures will be defined and compared on a parametric basis. It is planned that Phase II efforts will provide for detailed design and testing of an efficient support system.

Anticipated Results/Potential Commercial Applications as described by the awardee: Optimization of structural systems for large aperture, stretched membrane heliostats will alleviate the size constraints currently imposed by the support. Central receiver concentrator costs will decrease as structural systems become lighter and able to support larger reflectors. A reduction in concentrator price will ultimately provide a more cost-competitive solar thermal, central receiver system.

HIGH TEMPERATURE STRUCTURAL CERAMICS FOR HEAT ENGINES

105

Laser-Based Ultrasonic Excitation and Speckle Interferometric Detection Systems for Nondestructive Evaluation of High Temperature Ceramics—
American Research Corporation of Virginia, P.O. Box 3406, Radford, VA 24143-3406; 703-731-0836
Dr. Adel Sarrafzadeh, Principal Investigator
Mrs. Anne Churchill, Business Official
DOE Contract No. DE-AC05-87ER80459
Amount: \$49,898

The use of advanced materials such as ceramics, ceramic composites, and high temperature coatings has led to improved performance of critical heat engine and energy-related components and systems. However, the requirements for nondestructive evaluation (NDE) of ceramic materials resulting from complex geometry, inhomogeneity, reduced flaw size, and adverse processing environments have produced long inspection times and have reduced confidence in estimating component integrity and lifetime. One class of NDE sensors, based on photoacoustic generation and acousto-optic detection of ultrasound, offers important advantages over conventional NDE techniques. This program involves a novel laser-based excitation system employing photo-acoustic generation combined with laser speckle interferometric detection. Specific program objectives include the laser generation of ultrasound in advanced materials; investigation of methods to achieve a high speed, high resolution laser excitation system for integration with sensitive ultrasonic imaging systems; acquisition of families of test data for comparison with other noncontacting NDE methods; and design of a prototype system. The Phase I program should provide a noncontacting, in-process characterization technique for laser-based NDE of advanced ceramic materials for extensive development and test with structural components in high temperature heat engines during Phase II of the program.

Anticipated Results/Potential Commercial Applications as described by the awardee: The noncontacting laser-based interrogation system should result in improvements in NDE characterization of advanced ceramics during fabrication and in-service monitoring. The program should yield more efficient, cost-effective advanced structural ceramics for use in high-temperature gas turbine engines. Major commercial application of advanced high temperature,

structural ceramics has been predicted in cutting-tool inserts; turbocharger rotors; mechanical seals; and automotive valve guides, piston caps, bearings, and cylinder liners.

106

Synthesis of High-Strength Alumina Whiskers for Reinforcing Ceramic and Metallic Matrices—
Ceramatec, Inc., 2425 South 900 West, Salt Lake City, UT 84119; 801-972-2455
Dr. Raymond A. Cutler, Principal Investigator
Mr. John F. Grennan, Business Official
DOE Contract No. DE-AC05-87ER80462
Amount: \$49,885

Composites consisting of silicon carbide (SiC) whiskers in an alumina matrix have recently demonstrated the viability of using whiskers to toughen ceramics. Efforts to incorporate SiC whiskers into important oxide ceramics, such as zirconia, mullite, and cordierite have resulted in degradation of whiskers during fabrication. It is clear that high strength alumina whiskers would be advantageous to ceramic composites. Alumina whiskers are not commercially available, and previous research on the growth of such whiskers has shown limitations in the synthesis routes used to date. Alumina whiskers that are 1 to 5 microns in diameter and have an aspect ratio greater than 1000 have been fabricated. The planned Phase I research will investigate three novel synthesis routes and characterize the whiskers synthesized using electron microscopy, x-ray diffraction, and gravimetric techniques. The synthesis route showing the best yield and the potential for low cost will be investigated in further detail in Phase II. Research during Phase II will investigate reaction mechanisms, determine mechanical properties, and demonstrate the ability to incorporate alumina whiskers into a zirconia matrix ceramic composite. Phase III will concentrate on development of an economical process for alumina whisker production.

Anticipated Results/Potential Commercial Applications as described by the awardee: Potential applications include (1) improved high temperature (above 500°C) performance of zirconia ceramics for use as engine components and wear parts; (2) improved oxidation resistance, and hence, use temperature of ceramic whisker composites used as cutting tools; and (3) metal matrix composites with high stiffness for aircraft applications.

The Rapid Growth and Harvesting of SiC Whiskers from Composite Particles—Materials and Electrochemical Research Corporation, 4233 South Fremont Avenue, Tucson, AZ 85714; 602-746-9442
Dr. Cheng-Tsin Lee, Principal Investigator
Dr. Raouf O. Loutfy, Business Official
DOE Contract No. DE-AC03-87ER80526
Amount: \$50,000

The use of whiskers in metals and ceramics is well established and destined to play a major role in advanced high technology materials applications. The availability and cost of whiskers such as silicon carbide (SiC) is a key to the economic production and widespread use of advanced composite materials. Currently, whiskers are batch grown in 6- to 10-hour cycles using stainless steel powder as a seed catalyst to promote a vapor-liquid-solid (VLS) growth mechanism. The length and diameter (l/d) control of whisker growth is random, with very little process control to produce controlled whisker sizes. Advanced composites ideally require a controlled l/d whisker to produce high performance and reliable

composites. After a batch growth cycle, tedious and multiple step harvesting is required to separate the whiskers from powder growth and catalyst. The batch processing and harvesting results in high cost whiskers with a projected production cost of around \$100/lb. There is only one major U.S. whisker producer and several Japanese producers currently marketing whiskers in the United States at about \$250/lb. This program plans to investigate a continuous rapid growth process from a composite catalyzed particle with in situ continuous gas transport harvesting with the potential to produce SiC whiskers at near the cost of SiC powder.

Anticipated Results/Potential Commercial Applications as described by the awardee: SiC whiskers are now commercially utilized in alumina composite cutting tools and aluminum alloys in aerospace applications, despite their high cost and limited availability. A domestic source of low cost, high quality whiskers would dramatically expand advanced composites development and utilization, and would maintain the United States' technology leadership in high technology materials applications.

INDUSTRIAL SEPARATION, CONVERSION, AND RECOVERY PROCESSES

Ethanol-Water Fractionation by a Nonboiling Heat and Mass Transfer Process—Albers Research and Development Associates, 2626 East Arizona Baltimore Circle, Suite 23, Phoenix, AZ 85016; 602-955-9199
Mr. Walter F. Albers, Principal Investigator
Mr. Walter F. Albers, Business Official
DOE Contract No. DE-AC03-87ER80527
Amount: \$41,708

Feasibility and fundamental operation of an innovative nonboiling minimum energy heat and mass transfer device will be investigated. An ethanol/water binary system was selected because of its commercial importance. The heat and mass transfer device uses an inert carrier gas operating at atmospheric pressure to evaporate ethanol and water and then to condense water and ethanol in a manner so as to reuse the heat of vaporization and cause compositional changes potentially resulting in high product purities. This device is constructed of inexpensive materials.

Anticipated Results/Potential Commercial Applications as described by the awardee: The process and device should allow capital cost to be one-fourth that of conventional fractionators and energy usage to be on the order of the required heat of solution corresponding to product purity specification. Because of process and equipment simplicity, these savings would accrue to both the small and the large-scale user.

Reaction-Enhanced Extraction of Aromatics—KSE, Inc., P.O. Box 368, Amherst, MA 01004; 413-549-5506
Dr. J. R. Kittrell, Principal Investigator
Dr. J. R. Kittrell, Business Official
DOE Contract No. DE-AC02-87ER80524
Amount: \$49,888

The total U.S. commercial jet fuel market is about 11 billion gallons annually and is forecast to grow at a rate of 3% per year. Approximately 50% of the current jet product is limited by aromatics content

and/or smoke point. Future demand growth and trends in crude oil quality will require efficient processes for aromatics removal. Conventional extraction or catalytic hydrogenation processes exhibit deficiencies for this application, except in special circumstances. The technical feasibility of a unique reaction-enhanced extraction process is to be evaluated for this application in the planned program. The enhanced distribution coefficient permits extraction with higher yields and a reduced solvent-to-oil ratio, with associated cost and energy savings compared with alternative processes. This process appears to be economically viable, to provide substantial energy savings, and to provide a coproduct of high end-use value.

Anticipated Results/Potential Commercial Applications as described by the awardee: If the program is successful, it could provide energy savings of 1.7 trillion Btu annually, and could grow to 12 trillion Btu in the next decade. It will benefit the refining industry, now under stress, through improved profitability, employment, and energy savings. It can economically provide an incremental supply of jet fuel, beneficial to the transportation segment of the economy. It can improve the utility of heavy crude oils from off-shore California and from secure Western Hemisphere import sources.

110

Recovery of Organic Vapors from Printing and Painting Operations Using Surfactant-Enhanced Carbon Regeneration—Surfactant Associates, 2609 Barry Switzer Avenue, Norman, OK 73071; 405-325-4369

Mr. Bruce L. Roberts, Principal Investigator
Dr. Rex T. Ellington, Business Official
DOE Contract No. DE-AC05-87ER80512
Amount: \$50,000

Activated carbon is frequently used to absorb organic materials from air and water in many industrial operations. In particular, activated carbon is used to absorb volatile organics from the exhaust air in the printing and painting industries. A necessary part of such operations is the regeneration of the activated carbon with simultaneous recovery of the organic material, which is generally very inefficient except for highly volatile materials. Government regulations now restrict from these operations the allowable concentrations of volatile organic solvents that can be emitted to the atmosphere. It would be useful to recover the organics for reuse in the operation. An entirely new regeneration technique, called surfactant-enhanced carbon regeneration (SECR) is

being investigated for recovery of organics emitted by the printing and painting industry. With SECR, the absorber containing the used, spent carbon is treated with a concentrated surfactant solution. The organic material on the spent carbon is desorbed and solubilized in the surfactant solution. Then, the surfactant is precipitated and recycled to the process. Settling yields separation of the organic and the water. After flushing with water, the carbon is returned to service with drying for use in air streams. The process has potential for energy efficient, low toxicity, environmentally safe, low cost recovery of fugitive organic vapors with minimal handling of solid materials. In the Phase I work, organics used in printing/painting will be carried through all the process steps. Performance data will be obtained on every step, including rates and concentrations. The results will permit preliminary economic analysis to determine the competitive strength of SECR and justification for implementing Phase II.

Anticipated Results/Potential Commercial Applications as described by the awardee: Absorption of volatile organic solvent vapors on activated carbon is a relatively cost-efficient way in which these organic vapors may be removed from the air. However, the regeneration of the carbon after it is saturated is a major cost factor in the process. SECR is a new regeneration technique under study. This process could greatly improve the cost efficiency of the carbon regeneration phase of fugitive solvent recapture in printing, painting, and many other industries. It could also improve the economic viability of activated carbon processes for product recovery in other applications, such as bioseparations in biotechnology.

111

Biomethanation of Kraft Paper Mill Sludges and Liquid Effluents by Innovative Anaerobic Fermentation—Uintex Corporation, 4568 Highland Drive, #200, Salt Lake City, UT 84117-4263; 801-272-1111

Dr. Sambhunath Ghosh, Principal Investigator
Dr. Clark A. Lin, Business Official
DOE Contract No. DE-AC03-87ER80547
Amount: \$50,000

Phase I research will be a laboratory-scale demonstration of the technical merit of an innovative two-phase digestion process for the simultaneous biomethanation and stabilization of sludge and liquid effluents from kraft paper mills. Kraft mill waste was chosen because of the large number of kraft pulping plants. A process developed to convert kraft mill

waste to methane is also expected to be applicable for bioconversion of other types of paper mill wastes. Bioconversion energy could displace up to 30% of the purchased energy in a paper mill. The planned thermophilic two-phase process provides for (1) detoxification, solids hydrolysis, and neutralization in a slowly-stirred upflow first-stage acid reactor and (2) optimization of coupled acetogenic-methanogenic fermentation of the acetogenic end products in a hybrid upflow second-stage reactor containing a stationary packed bed of inclined tubes. The reactors effect enhanced solids retention allowing high-efficiency conversion of feeds at lower hydraulic retention times (HRT) (relative to 20-40 days for conventional digestion of paper mill sludge). Phase I research will focus on demonstration of a stable and efficient operation at a system HRT of about 6 days. Alkali scrubbing of first-stage digester gas and its recirculation to the head space would detoxify the effluent (methane digester feed). Feed neutralization and nutrient retention within the overall system will be effected by recycling methane digester effluents to the first-stage reactor. The digestion system effluent will

be treated in a trickling filter with the excess sludge returned to the acid digester. Phase II of the project will be concerned with process scale-up and pilot plant demonstration needed to finalize design and operating procedures for commercial plants.

Anticipated Results/Potential Commercial Applications as described by the awardee: Phase I studies are designed to prove the technical feasibility of the planned process in terms of operability without toxicity effect and to provide biomethanation and stabilization efficiencies. At the end of Phase II, design details and commercialization plans will be available. There are about 500 pulp and paper mills in the United States. About 40% of these mills practice kraft pulping. The planned process would be potentially applicable to simultaneous biomethanation and stabilization of effluents and sludges from these mills. The U.S. paper and pulp industry purchases about 2.5 quads/yr. Application of the planned process could in theory displace about 30% of the purchased energy amounting to significant energy savings.

APPENDIX A

Alphabetical List of Awardees

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Alabama Cryogenic Engineering, Inc. 29 Dr. John B. Hendricks, Business Official P.O. Box 2451 Huntsville, AL 35804 (205) 536-8629	Ceramatec, Inc. 12,13,97,106 Mr. John F. Grennan, Business Official 2425 South 900 West Salt Lake City, UT 84119 (801) 972-2455
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American Research Corporation of Virginia 105 Mrs. Anne Churchill, Business Official P.O. Box 3406 Radford, VA 24143-3406 (703) 731-0836	Complex Carbohydrate Corporation 19 Dr. Alan Darvill, Business Official 2351 College Station Road; Suite 512 Athens, GA 30605 (404) 546-7797
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Material Concepts, Inc.	55	Radiation Monitoring Devices, Inc. and	46
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Materials Sciences Corporation	73	(617) 494-0335	
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Odetics, Inc.	66,67	(615) 483-0228	
Mr. Leonard W. Welsch, Business Official		RhoMed, Inc.	24
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Plasma Physics Corporation	14	Los Alamos, NM 87544	
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(505) 984-1322		(504) 652-1127	
Spectracom	100	Technor, Inc.	91
Ms. Kimberly L. Eskenas, Business Official		Dr. Robert A. Perry, Business Official	
P.O. Box 3178		524 Hazel Street	
Simi Valley, CA 93063		Livermore, CA 94550	
(818) 341-4087		(415) 443-5078	
Spectral Sciences, Inc.	8	Thermacore, Inc.	76
Dr. Fritz Bien, Business Official		Mr. Donald M. Ernst, Business Official	
111 South Bedford Street		780 Eden Road	
Burlington, MA 01803		Lancaster, PA 17601	
(617) 273-4770		(717) 569-6551	
Spire Corporation	15,33,45,58,90	Unitex Corporation	111
Mr. Richard Gregorio, Business Official		Dr. Clark A. Lin, Business Official	
Patriots Park		4568 Highland Drive, #200	
Bedford, MA 01730		Salt Lake City, UT 84117-4263	
(617) 275-6000		(801) 272-1111	
Supercon, Inc.	34,35,59,60	Universal Energy Systems, Inc.	16
Ms. Elaine Drew, Business Official		Mr. Larry E. Clay, Business Official	
830 Boston Turnpike		4401 Dayton-Xenia Road	
Shrewsbury, MA 01545		Dayton, OH 45432	
(617) 842-0174		(513) 426-6900	
Surfactant Associates	110	Visual Interface Corporation	69
Dr. Rex T. Ellington, Business Official		Dr. John Tracy, Business Official	
2609 Barry Switzer Avenue		1917 Coventry Court	
Norman, OK 73071		Thousand Oaks, CA 91362	
(405) 325-4369		(805) 495-6837	
Synetics Corporation	42	Xi Magnetix, Inc.	17
Mr. Martin Wapner, Business Official		Dr. John L. Wallace, Business Official	
80 Main Street		R. D. 4 Box 457	
Reading, MA 01867		Coatesville, PA 19320	
(703) 848-2550		(215) 347-1768	

References denote entry numbers.

APPENDIX B

State Listing of Awardees

Alabama 29
Arizona 71, 107, 108
California 9, 10, 18, 43, 52, 66, 67, 69, 79, 81, 82, 83, 91, 98, 100
Colorado 53, 101
Connecticut 11, 25, 27, 48, 99
Florida 26
Georgia 19, 61
Illinois 32, 38, 39, 95
Louisiana 84
Maryland 22, 37
Massachusetts 4, 5, 8, 15, 21, 30, 33, 34, 35, 42, 45, 46, 49, 50, 51,
58, 59, 60, 62, 72, 85, 86, 88, 89, 90, 109
Michigan 28, 63
New Hampshire 20, 31, 75
New Jersey 103
New Mexico 7, 24, 41, 93
New York 14, 36, 40, 54
North Carolina 80
Ohio 16, 55
Oklahoma 96, 110
Oregon 1, 2, 3
Pennsylvania 17, 57, 73, 76, 77, 87
Tennessee 23, 47, 64, 74
Texas 68, 94, 102, 104
Utah 12, 13, 65, 92, 97, 106, 111
Virginia 44, 56, 70, 105
Washington 6, 78

References denote entry numbers.

APPENDIX C

Proposal Submissions and Awards Listed By States, Territories, and Possessions

	Proposals Submitted	Number Selected		Proposals Submitted	Number Selected
Alabama	9	1	Montana	3	0
Arizona	16	3	Nebraska	2	0
Arkansas	1	0	Nevada	6	0
California	200	15	New Hampshire	5	3
Colorado	33	2	New Jersey	23	1
Connecticut	17	5	New Mexico	17	4
Delaware	2	0	New York	27	4
District of Columbia	7	0	North Carolina	14	1
Florida	19	1	North Dakota	1	0
Georgia	13	2	Ohio	32	2
Hawaii	1	0	Oklahoma	8	2
Idaho	6	0	Oregon	7	3
Illinois	28	4	Pennsylvania	57	6
Indiana	6	0	Puerto Rico	1	0
Iowa	4	0	South Carolina	3	0
Kansas	1	0	Tennessee	41	4
Kentucky	2	0	Texas	39	4
Louisiana	17	1	Utah	26	7
Maine	1	0	Vermont	1	0
Maryland	48	2	Virginia	22	4
Massachusetts	115	26	Washington	23	2
Michigan	17	2	West Virginia	2	0
Minnesota	7	0	Wisconsin	7	0
Missouri	2	0	Wyoming	3	0

Note: Although eligible in each case to participate, there were no submissions from Alaska, Mississippi, Rhode Island, South Dakota, the Commonwealth of the Northern Mariana Islands, and the Trust Territory of the Pacific Islands.