DOE/ER-0391

Advanced Energy Projects FY 1988 Research Summaries

September 1988

U.S. Department of Energy
Division of Advanced Energy Projects
Office of Basic Energy Sciences
Office of Energy Research

DOE/ER-0391
Dist. Category UC-2-13

Advanced Energy Projects FY 1988 Research Summaries

September 1988

U.S. Department of Energy
Division of Advanced Energy Projects
Office of Basic Energy Sciences
Office of Energy Research
Washington, D.C. 20545

TABLE OF CONTENTS

OFFICE OF BASIC ENERGY SCIENCES

DIVISION OF ADVANCED ENERGY PROJECTS (AEP)

Program Description

What projects are supported?

This Division supports exploratory research on novel concepts related to energy. The research is usually aimed at establishing the scientific feasibility of a concept and, where appropriate, also at estimating its economic viability. Because projects supported inevitably involve a high degree of risk, an indication of a high potential payoff is required. An immediate, specific application of the concept is not an absolute prerequisite for consideration; thus, for example, proposers of schemes leading to the development of gamma-ray lasers are not required to justify their proposals by discussing potential applications of such lasers.

The concepts supported are typically at too early a stage of scientific verification to qualify for funding by DOE programs responsible for technology development. Where doubt exists, such programs are consulted, prior to proposal consideration by AEP, in order to establish their possible interest in the project.

Projects not supported

The AEP Division does not support ongoing, evolutionary research. Neither does it support large scale demonstration projects.

Period of support and funding levels

By design the period of support is finite, generally not exceeding three years. It is expected that, following such a period, the concept will either be at a stage where it can be supported by a technologically appropriate organization or branch of DOE, or else it will be dropped. Annual funding level for projects varied from about $30,000 to a maximum in the $400,000 range.

Who can propose?

Unsolicited proposals can be submitted by universities, industrial organizations, nonprofit research institutions or private individuals. Consideration is also given to ideas submitted by scientists working at national laboratories.

Proposal evaluation

Awards are based on the results of an evaluation process which usually involves a review by external reviewers. Regardless of the outcome of the evaluation, proposers receive copies of reviewers' reports.

Questions asked of the reviewers depend on the subject of the proposal. Some typical questions are listed below:

1. Is the proposed concept new? How does it compare with other work in the field?

2. Are there basic flaws in the scientific (technical) arguments underlying the concept?

3. Are the technological requirements of the proposed concept, including material requirements, within the realm of either present or near term future capabilities?

4. Is there anything about the concept which makes its economics manifestly untenable, even under reasonably optimistic assumptions?

5. Is the anticipated benefit to the public high enough to warrant the Government's involvement in the R&D effort?

Preproposals desired

It is suggested that before a formal proposal is prepared, the proposer should submit a brief outline of the proposed work. The outline should provide enough background information to enable a decision as to whether or not the proposed work programmatically fits the mission of AEP.

Proposals

Once a programmatic interest of AEP in the proposed project has been established, a proposal should be submitted along the guidelines specified in the "Office of Energy Research Special Research Grants Program Guide for the Submission of Applications." Each proposal must contain:

- A cover page.

- A 200-300 word abstract, written in plain English, describing the essence of the project in terms understandable to a layman. The abstract should be in a form suitable for inclusion in DOE program presentations, such as this brochure.

- A technical discussion of the proposed concept and a description of the proposed work. While the discussion should be kept brief, there is no formal limitation on the number of pages allotted to this section of the proposal. Since it is this section that will form the basis for the evaluations by technical reviewers, the proposer is urged to make certain that all aspects of the proposed project which are relevant to forming a judgment of the project's merits are adequately covered.

- A statement of work specifying all tasks to be performed in the course of the proposed work. A sample statement of work can be found on page 28.

- Description of available facilities.

- Resumes of key personnel.

- Detailed information on any support for the proposed or related work, past, present or anticipated, including proposals submitted, or about to be submitted, to other organizations.

- A cost estimate for the proposed effort.

<u>Further information</u>

Inquiries should be addressed to:

Dr. Ryszard Gajewski, Director
Division of Advanced Energy Projects
Office of Basic Energy Sciences
ER-16, GTN
Department of Energy
Washington, DC 20545

Phone: 301/353-5995

<u>Heavy Ion Fusion Accelerator Research</u>

In addition to the program described above, the Division manages DOE's Heavy Ion Fusion Accelerator Research (HIFAR) program. The HIFAR objective is to acquire an appropriate data base for future decisions on heavy ion fusion based on induction linac drivers. Inquiries regarding HIFAR should be addressed to Dr. Walter M. Polansky, HIFAR Program Manager, ER-16, GTN, Department of Energy, Washington, DC 20545, phone 301/353-5935.

OFFICE OF BASIC ENERGY SCIENCES

DIVISION OF ADVANCED ENERGY PROJECTS

Summaries of Projects Active in FY 1988

This section contains brief summaries of the projects active in this Division during Fiscal Year 1988 (October 1, 1987 - September 30, 1988). The intent of this compilation is to provide a convenient means for quickly acquainting an interested reader with the program in Advanced Energy Projects. More detailed information on research activities in a particular project may be obtained by contacting directly the principal investigator identified below the project title. Some projects will have reached the end of their contract periods by the time this book appears, and will, therefore, no longer be active. Those cases in which work was completed in FY '88 are indicated by the footnote: *Project completed. The annual funding level of each project is shown.

1. ENERGY RELATED APPLICATIONS OF ELEMENTARY PARTICLE PHYSICS

UNIVERSITY OF ARIZONA
Tucson, Arizona 85721

Johann Rafelski
Department of Physics

Date Started: March 1, 1988

$296,000

Anticipated Duration: 3 years

Muon catalyzed fusion proceeds via a cycle of complex quantum mechanical processes and leads to at least 150 d-t fusions per muon, releasing an energy equivalent of more than 30 times the mass of the muon. The economical applications thus demand that a method be found facilitating efficient muon production in elementary particle processes. Another way of improving the economics of the muon catalyzed fusion process is to accelerate the reactions by the proper choice of density, target composition, and magnetic fields. The influence on the cycle dynamics of vacuum polarization splitting in the excited muonic atom levels needs to be ascertained. Muon regeneration processes after muons are bound ('stuck') to alpha particles are important in determining the maximum number of fusions a muon can facilitate. In particular, regeneration in low temperature plasmas is an open issue. The greatest puzzle of muon catalyzed fusion is the exact understanding of the sticking process, which is a complex atomic/nuclear phenomenon, in which the 'spectator' of the fusion is caught by the nuclear fusion product. Both the theoretical formulation and numerical analysis of this process present formidable challenges to the understanding of few body reactions. Because antiprotons can be viewed as the only 'stable' storage of muons due to their annihilation into pions which decay into muons, antiproton annihilation phenomena may play a major role in future muon catalyzed fusion applications. In this context it is important to understand the processes leading to the deposition of annihilation energy in matter and the interactions of low energy antiprotons with matter and nuclei.

2. INVESTIGATION OF MUON FUSION CYCLE ENHANCEMENT (LASER ENHANCEMENT OF RESONANT MUOMOLECULAR FORMATION)

BROOKHAVEN NATIONAL LABORATORY
Upton, New York 11973

Hiroshi Takahashi

Date Started: October 1, 1987

$50,000

Anticipated Duration: 26 months

To use muon catalyzed fusion for energy production, it is desirable to get a high muon catalyzed fusion cycle rate even in the deuterium-tritium low density mixture. It has been demonstrated that muon catalyzed cycle rates increase rapidly with increased deuterium-tritium gas density. This experimental result is explained by noting that the dtμ molecular formation rate, which is the bottle neck of the cycle, is enhanced by giving the excess energy of this reaction to the third body of surrounding molecules. Using the coherent electromagnetic wave radiation, like laser radiation, as the third body, the dtμ molecular formation rate might be enhanced. The purpose of this program is to explore the characteristic mode of the coherent radiation (intensity and frequency) for such enhancement of the molecular formation rate, as well as other means for such enhancement.

3. GENERATION OF RADIATION BY INTENSE PLASMA AND ELECTROMAGNETIC UNDULATORS

UNIVERSITY OF CALIFORNIA, LOS ANGELES
405 Hilgard Avenue
Los Angeles, California 90024

Chan Joshi

Date Started: July 1, 1987

$300,000

Anticipated Duration: 3 years

This program involves the generation of short wavelength, UV-VUV, radiation by intense plasma and electromagnetic undulators. In this concept a relativistic electron beam is wiggled by either the oscillating electric field of an intense plasma density wave or by an electromagnetic wave causing it to radiate. Using these schemes it is proposed to generate tunable radiation in the 1500 Å - 3 μm range from an electron beam of only 1.5 MeV energy. The plasma wave with an effective wiggler strength parameter $a_w \approx 0.1$, wavelength $\lambda_w \approx 100$ μm and number of periods $N \approx 100$ will be excited by resonantly beating two laser beams in a plasma. The electrons are made to wiggle transversely at the plasma frequency ω_p by injecting them parallel to the plasma wavefronts. Because of relativistic Doppler shift the radiated frequency is upshifted to $2\gamma^2\omega_p$. For even shorter wiggler wavelengths a powerful CO_2 laser, $\lambda_w \approx 10$ μm, $a_w \approx 1$, will be used. By counter propagating this laser beam with the electron beam it is proposed to generate 1500 Å VUV radiation. Because of the high wiggler strengths, some harmonic generation is expected. An applications study will also be undertaken to identify technologies which would likely be impacted by these sources.

4. *MUONIC MOLECULAR STRUCTURE, μ-STICKING PROBABILITIES AND FUSION RATES FOR MUON CATALYZED FUSION

CALIFORNIA STATE UNIVERSITY, LONG BEACH
1250 Bellflower Blvd.
Long Beach, California 90840

Chi-Yu Hu
Physics/Astronomy Department

Date Started: August 1, 1986

$60,000

Anticipated Duration: 2 years

In the muonic molecules such as $(dt\mu)^+$, $(dd\mu)^+$, the muon "confines" the two nuclei in a region small enough that fusion can occur. The average number of fusions induced by each muon determines the upper limit on energy production. In order to predict the average number of fusions per muon and other properties in the muon-catalysis cycle, it is essential to understand the details of the muonic molecular structures. The purpose of this project is to make extremely accurate calculations of the $(dt\mu)^+$ and $(dd\mu)^+$ molecular structures and then to use these wave functions to determine fusion rates, μ-sticking probabilities and other parameters necessary to understand the mesomolecular formation process and the fusion process. In this collaboration with the theoretical and the experimental teams at Brigham Young University, Los Alamos National Laboratory, and the Lawrence Livermore National Laboratory, the ultimate goals are to understand completely the muonic molecular structures and the muon-catalysis cycle.

*Project completed.

5. MUON-CATALYZED FUSION IN GASES OF HD AND H_2 + D_2 MIXTURES

CALIFORNIA STATE UNIVERSITY, LOS ANGELES
5151 State University Drive
Los Angeles, California 90032

Konrad Aniol
Physics Department

Date Started: September 15, 1986

$28,000

Anticipated Duration: 39 months

Current measurements of muon induced fusion in deuterium-tritium mixtures show that the sticking probability is about 0.4%. At this level of sticking, other processes, such as the formation of $dd\mu$ or $pd\mu$ muonic molecules, have significant effects on the loss of muons from the fusion cycle. The molecular formation rates of $dd\mu$ and $pd\mu$ are about 100 times smaller than that of the $dt\mu$. Nevertheless, because of their substantially larger sticking probability, they are important sources of muon loss at the tenth of a percent level. Measurements have been made of the relative formation rates of $dd\mu$ and $pd\mu$ molecules in gas samples of H_2 + D_2 and HD. Substantially different temperature dependences of $dd\mu$ formation rates in these two gas samples were observed, but not of the type predicted by theory. In addition, temperature dependence was observed in $pd\mu$ formation more pronounced than predicted, and a difference in absolute yield of $pd\mu$ formation between HD and H_2 + D_2 where none was anticipated. It is planned to remeasure the $dd\mu$ and $pd\mu$ rates in a new target cell over a larger temperature range. It is important to verify, in a new experimental set-up, whether the preliminary experimental results are correct.

6. ACCURATE ALPHA STICKING FRACTIONS FROM IMPROVED THREE-BODY CALCULATIONS RELEVANT FOR MUON CATALYZED FUSION

UNIVERSITY OF DELAWARE
Newark, Delaware 19716

Krzysztof Szalewicz
Department of Physics

Date Started: May 1, 1988

$93,000

Anticipated Duration: 19 months

In the last decade muon catalyzed fusion has been a subject of intensive research efforts worldwide. Recent experiments have shown that a single muon can catalyze more than 150 fusions. At present the major bottleneck of the muon catalyzed cycle as applied for energy production seems to be sticking of the muons to the alpha particles synthesized in the nuclear reactions. Stuck muons are lost for further fusions. The probability of this sticking is being theoretically investigated. The muonic molecular ions are described by highly accurate three-body wave functions. The nuclear effects are included by imposing boundary conditions on the wave functions at the nuclear radius. To add flexibility in this region the basis sets contain irregular terms, i.e. negative powers of the nuclear distance. Alternatives to the classical expression for the sticking amplitude are being derived. Other topics of the work include calculations of the finite size corrections to energy levels of muonic molecules, improved determination of the molecular formation rates, and investigation of the role of the internal resonances in this formation.

7. ALPHA STICKING FRACTION CALCULATIONS IN MUON CATALYZED FUSION

DUKE UNIVERSITY
Durham, North Carolina 27706

L.C. Biedenharn
Physics Department

Date Started: September 15, 1986

$54,000

Anticipated Duration: 39 months

Recent experiments on deuterium-tritium fusion, catalyzed by muons, show an unexpectedly large number of fusions per muon. This indicates that thermonuclear energy production, via muon catalyzed fusion, might be considered as a possibility. The single most important parameter characterizing this process is the "alpha sticking fraction" W_s (the fraction of the muons lost by capture on the alpha particle per fusion cycle) since the average number of fusions per muon--which determines the feasibility for energy production--cannot exceed $(W_s)^{-1}$. A precise calculation of W_s is now important for determining a theoretical upper limit for feasibility studies; no such calculation currently exists. A cooperative program will be conducted for an accurate calculation of W_s. The calculation of W_s involves two different disciplines: nuclear physics (the $^5He(3/2+)$ resonance is crucial) and molecular physics. Eigenphase-shift techniques will be used to develop nuclear wavefunctions in the critical short distance regime.

8. INVESTIGATIONS AND CALCULATIONS TOWARDS INCREASING THE EFFICIENCY OF MUON CATALYZED FUSION

UNIVERSITY OF FLORIDA
Gainesville, Florida 32611

H. J. Monkhorst
Department of Physics

Date Started: May 1, 1988

$105,000

Anticipated Duration: 51 months*

The phenomenon of muon catalyzed fusion offers an intriguing alternative to conventional fusion approaches for achieving thermonuclear energy production. The entire process, from entry of a muon into a mixture of hydrogen isotopic molecules (mainly made up of deuterium and tritium) to fusion reactions, involves several, subtly interlocking atomic, molecular, and nuclear physics effects. To fully understand and describe these effects, concepts and computational techniques from these disciplines have to be brought together. With quantitative explanations at hand ways could be identified to increase the number of induced fusions during a single muon's life time. This is the goal. Effort will be concentrated on two aspects in the muon catalyzed fusion cycle: nuclear effects on the "alpha sticking fraction" W_s and relativistic corrections to the binding of weakly bound muonic molecules containing deuteron and triton nuclei. It is crucial to know the W_s value a priori since its inverse determines the maximum number of fusions a single muon can induce (and hence the efficiency of muon catalyzed fusion), and its experimental determination is difficult. There are various hints that nuclear effects can be large, and can possibly be favorably influenced. Using experimental d-t scattering information, high-accuracy nuclear-molecular physics calculations will be performed. The theory is subtle, but now well understood and computable. Precise knowledge of relativistic effects on the weakly bound states will make it possible to fully describe, and subsequently "fine-tune," the dependence of muon molecular formation rates on temperature, density, and composition of the hydrogen isotopic mixture in the fusion reactor vessel. High accuracy is required and the theory and calculations should include all relativistic corrections.

*Includes no-cost extension.

9. A VISIBLE TUNABLE SOURCE

HUGHES AIRCRAFT COMPANY
P.O. Box 9399, M/S 3C923
Long Beach, California 90810

I-Fu Shih
Advanced Products Laboratory

Date Started: September 1, 1985

$132,000

Anticipated Duration: 39 months*

The objective of this program is to further understand the Salisbury-Smith-Purcell effect so that useful devices based on this effect can be developed. Salisbury-Smith-Purcell radiation occurs when an electron beam grazes a conducting grating. A tunable radiation source based on the Salisbury-Smith-Purcell effect could have wide-spread applications; for example, such a device can be used in interferometric sensors for acoustic, electromagnetic, pressure, or temperature sensing. These sensors can be used for geophysical exploration, and for a broad class of diagnostic, test, or control equipment. This program will focus on a feature of Salisbury's model that has not been exploited to date. The Salisbury model suggests that it is important to use a low divergence electron beam and to reflect some of the electrons from the grating surface to form sheets of periodic space charge above the grating. Both theoretical and experimental investigations are performed. The theoretical task is to refine the preliminary analysis to more accurately predict the radiation characteristics. The experimental task is to assemble an apparatus and to characterize the radiation.

*Includes no-cost extension.

10. MECHANISTIC STUDY OF THE EFFECT OF MAGNETIC FIELDS ON SCALE FORMATION

J.L. Katz
Department of Chemical Engineering

THE JOHNS HOPKINS UNIVERSITY
Baltimore, Maryland 21218

$71,000

Date Started: September 1, 1985

Anticipated Duration: 45 months*

This project involves investigation of the inhibition of scale formation by magnetic water treatment. Although commercial magnetic treatment devices are available, there is major controversy whether it works and how it works. Nonetheless, such devices have attracted great interest because, if effective, they are easy to use, reliable and very inexpensive. This project involves the testing of a mechanism which is able to account for all experimentally observed facts. Experiments show that both divalent and trivalent iron in trace amounts strongly inhibit the growth of calcite ($CaCO_3$) from supersaturated solution. Since most scale deposits consist of calcite, iron may play a critical role in controlling the amount and tenacity of scale deposits. The various ways in which a magnetic water treatment device may produce the necessary iron to poison calcite scale nucleation and growth will be investigated.

*Includes no-cost extension.

11. *APPLICATION OF PERMANENT MAGNETS TO ACCELERATOR TECHNOLOGY AND GENERATION OF RADIATION WITH ELECTRON STORAGE RINGS AND FREE ELECTRON LASERS

Klaus Halbach

LAWRENCE BERKELEY LABORATORY
Building 80-101
Berkeley, California 94720

$296,000

Date Started: October 1, 1985

Anticipated Duration: 3 years

Because of saturation properties of soft ferromagnetic materials and of problems associated with the cooling of coils, the magnetic field strength achievable in small working volumes becomes smaller as the linear dimensions of an electromagnet become smaller. Since permanent magnets do not have the coil cooling problems, they can produce much larger fields than electromagnets when magnetically relevant dimensions have to be small. For that reason, permanent magnet undulators/wigglers and charged particle beam handling magnets have been developed over the last few years. It is the purpose of this project to further explore the magnet devices with regard to their reliability and field quality. Consequently, the effect of construction and material tolerances on field quality will be investigated, and improved construction methods will be developed. In addition, work will proceed to incorporate permanent magnet materials into electromagnets, to make it possible to produce with permanent magnets assisted electromagnets fields of the same strength that permanent magnets produce. This work is particularly important for tapered undulators in free electron lasers, where one needs the combination of permanent magnet strength and electromagnet variability. In addition to developing new concepts, the tools employed to achieve these goals (a combination of analytical models, computer analysis and synthesis, and experimental work) will be perfected.

*Project completed.

12. ACCELERATION OF A COMPACT TORUS PLASMA RING

LAWRENCE LIVERMORE NATIONAL LABORATORY
P.O. Box 5511
Livermore, California 94550

Charles Hartman

Date Started: July 1, 1985

$446,000

Anticipated Duration: 4 years

This project has the objective of demonstrating acceleration of plasma rings confined by the dipole and entrapped B magnetic fields of a compact torus. The 6 m long accelerator is in the form of a coaxial rail-gun with the plasma ring, which acts as a moving short, accelerated by a 250 kJ capacitor bank. Successful acceleration will yield 10^{-5} to 10^{-3} gram plasma rings with 100 kJ kinetic energy and velocities up to about 5×10^8 cm/sec. Rapidly moving plasma rings will be tested for focusing by injecting them into a conducting core where eddy currents will compress the magnetic field and confined plasma to small size. This new type of collective accelerator employing magnetic confinement will allow access to power, power density, and energy density regimes heretofore inaccessible in the laboratory. Following demonstration of acceleration, applications can be tested, including rapid compression of rf fields to produce an ultra high power rf source, nanosecond generation of high temperature radiation, a fast opening in megampere switch, and, in a scaled up accelerator, focusing to produce an efficient, simple inertial fusion driver.

13. *DETECTION AND ENRICHMENT OF FRACTIONALLY CHARGED PARTICLES IN MATTER

LAWRENCE LIVERMORE NATIONAL LABORATORY
P.O. Box 808, L-482
Livermore, California 94550

Charles D. Hendricks
Y Division, Laser Program

Date Started: May 1, 1982

$218,000

Anticipated Duration: 6-1/2 years

This project is an experimental search for fractionally charged particles in matter. Such particles may be a manifestation of free quarks. At the heart of the experiment is a charge-to-mass measurement on very uniform mass particles. Thus, a measurement of q/m will yield relative values of the charge of the particles. Because most of the particles should have charges which differ by integer values of one electron charge, only relative charge measurements between particles need be made to determine the presence of fractional charges. Liquid drops which are about 25 micrometers in diameter and spaced about 1600 micrometers apart are made at a rate of approximately 10^4 drops per second. These values depend on the particular parameters set into the experiment as it is being done. The drops traverse the space between two vertical, parallel plates which may be maintained at a DC potential difference up to about 60 kV. With no potential between the plates the drops travel along a straight vertical line downward between the plates. With a high potential between the plates, the drops are deflected transversely along paths which depend on the charge on each drop. Data is being taken to determine the relative charges on the drops and, thus, determine the presence or absence of fractional charges.

*Project completed.

14. THEORETICAL STUDY OF MUON-CATALYZED FUSION

LOS ALAMOS NATIONAL LABORATORY
MS-J569
Los Alamos, New Mexico 87545

James S. Cohen
Theoretical Division

Date Started: December 29, 1983

$303,000

Anticipated Duration: 6 years

This study is designed to formulate a detailed description of the muon-catalyzed fusion cycle, with the objectives of aiding the experimental program and obtaining parameters needed to evaluate the ultimate limitations on energy production. Nuclear fusion occurs when a negative muon (μ^-, an unstable particle about 200 times as massive as the electron) is stopped in a high-density mixture of deuterium and tritium and the small $dt\mu$ mesomolecule is formed. Experiments at the Los Alamos Meson Physics Facility have detected 150 fusions per muon. Some unexpected transient behaviors and dependencies of the mesomolecular-formation and muon-loss rates on temperature and target density have been observed; understanding of these effects may lead to still higher yields. The physical problems being addressed theoretically include muon capture and transfer, muonic molecule formation (with nonthermal and hyperfine effects) and structure, and muon loss (to impurities as well as helium) and regeneration. In collaboration with the experimental team, tests of theoretical predictions are planned.

15. NUCLEAR EXCITATION BY A HIGH-BRIGHTNESS UV LASER

LOS ALAMOS NATIONAL LABORATORY
Los Alamos, New Mexico 87545

Peggy L. Dyer
Physics Division

Date Started: July 1, 1986

$358,000

Anticipated Duration: 3 years

In the conceptual two-step pumping scheme for a gamma-ray laser, the most difficult remaining problem lies in exciting nuclei from long-lived storage isomers to nearby short-lived states (that will then spontaneously decay to upper lasing levels), without destroying the solid state structure required for the Mossbauer effect and for Borrmann modes. A novel mechanism recently proposed for this transfer will be experimentally investigated: nuclear excitation by electrons driven to oscillate collectively by a bright, picosecond ultraviolet laser. As a test case it will be attempted to excite the 75-eV isomer of ^{235}U, the excitation signal being delayed internal conversion electrons. Following parameter-dependence studies with a vapor target in a collision-free environment, nuclear excitations in solid substrates of the crystalline form required for a gamma-ray laser will be investigated. Finally, nuclear isomeric targets will be used, in preparation for first experiments to look for stimulated emission in nuclei.

16. *ANTIPROTON TECHNOLOGY

LOS ALAMOS NATIONAL LABORATORY
Los Alamos, New Mexico 87545

M. V. Hynes
Physics Division

Date Started: October 1, 1985

$499,000

Anticipated Duration: 3 years

From the initial observation of the antiproton in 1955 until the present, matter-antimatter annihilation as a compact energy source has been at best a visionary concept whose realization appeared beyond reach. A number of technological developments in both particle and atomic physics have brought the prospect of antimatter as an energy source much closer. The possibility now exists for performing experiments with the objective of storing substantial numbers of cold antiprotons, a critical step toward an antimatter energy source. As a part of experiment PS200 at CERN to measure the gravitational acceleration of antiprotons a number of interrelated problems central to evaluating prospects for antimatter storage as a potential advanced energy source will be investigated both experimentally and theoretically. These are: 1) demonstrate the storage of low temperature protons, antiprotons and $^{-}$H ions externally injected into a Penning type ion trap, 2) the cooling of trapped antiprotons to low temperatures ($\leq 10°K$), 3) trap a substantial quantity of antiprotons and release them in a controlled manner, and 4) carry out theoretical investigations in condensed matter, nuclear, and particle physics to establish a framework for further experimentation with low temperature antiprotons relevant to improved storage concepts.

*Project completed.

17. EXPERIMENTAL INVESTIGATION OF MUON-CATALYZED FUSION

LOS ALAMOS NATIONAL LABORATORY
P.O. Box 1663
Los Alamos, New Mexico 87545

Melvin Leon
MP Division

Date Started: October 1, 1985

$840,000

Anticipated Duration: 50 months

The remarkable ability of a single negative muon to catalyze many d-t fusions has given rise to speculations about the possibility of harnessing this reaction for practical power production. In order to put such discussions on a sound basis, it is essential that as complete an understanding as possible be developed of the subtle and intricate molecular physics involved. To this end, it is intended to investigate the physics of muon-catalyzed fusion, continuing the experimental program at LAMPF of the Brigham Young University-Los Alamos National Laboratory-Idaho National Engineering Laboratory collaboration. Our long range goals are to understand completely the muon-catalysis cycle, and to determine the maximum number of d-t fusions that can be obtained from a single negative muon.

18. DEVELOPMENT OF HIGH-REFLECTANCE MIRRORS FOR THE XUV

LOS ALAMOS NATIONAL LABORATORY
P. O. Box 1663, MS J564
Los Alamos, New Mexico 87545

Brian E. Newnam
Chemical and Laser Sciences Division

Date Started: October 1, 1987

$450,000

Anticipated Duration: 2 years

The object of this project is to develop broadband, high-reflectance mirrors for the extreme-ultraviolet and soft x-ray regions which extend from 10 nm to 100 nm. These are urgently needed for a number of laser schemes that involve resonators, e.g. XUV free-electron lasers, and for steering reflectors for synchrotron light sources. The approach used is to exploit the principle of total external reflection on multiple-facet metal surfaces to turn an optical beam by 180°. With certain metals (Al, Si, Rh, Ag) it is possible to attain retroreflectance ≥40% over the 35- to 100-nm and 10- to 14-nm spectral ranges. Preliminary experiments at Los Alamos have verified the feasibility of this approach at 58 nm for Al and Si surfaces in a UHV environment. The sequence of experiments will include: 1) spectral reflectance measurements on prototype, multifacet Al and Si reflectors over the 30- to 100-nm range, 2) evaluation of methods to control and/or renew the retroreflector surfaces, 3) extending the experiments to metal-reflector candidates (Rh, Ag) below 30 nm, and 4) transfer of the experiments to a large (60-cm dia.) UHV chamber to coat and test practical-size reflectors with 9 to 10 reflector facets.

19. SUPERCONDUCTIVE ELECTRIC MOTOR

LOS ALAMOS NATIONAL LABORATORY
MS G-770
Los Alamos, New Mexico 87545

David S. Phillips
MST Division

Date Started: October 1, 1987

$394,000

Anticipated Duration: 15 months

The goal of this program is to evaluate the concept of an electric motor utilizing superconducting ceramic elements, certainly in the field coils and probably in the armature. This motor will probably be "homopolar" in geometry, since that system minimizes the AC disturbance experienced by the conductors. It will probably be fabricated by "macro-composite" technology within or on top of normal ceramic structural members. Several technological difficulties seem to impede this development - they will be addressed in turn. First, the critical current densities in ceramic superconductors are disappointingly low, calling for investigation of improved flux pinning routes based on both precipitation and grain-size control. Second, the large scale composite ceramic processing technology envisioned for this application is itself unusual and requires a body of chemical compatibility data not yet extant. Research is needed in high temperature phase equilibria to help identify plausible ceramic matrices. Finally, the basic motor geometries previously envisioned for use with lower temperature metallic superconducting windings are largely dominated by the refrigeration equipment required to attain those low temperatures. Both the relaxed geometries apparently permitted by the higher temperature ceramic conductors and the refrigeration requirements remaining must be considered in the final choice of a design.

20. BIOLOGICAL X-RAY HOLOGRAMS

MCR TECHNOLOGY CORPORATION
P.O. Box 10084
Chicago, Illinois 60610

Keith Boyer

Date Started: September 1, 1986

$249,000

Anticipated Duration: 39 months*

A new ultrahigh brightness x-ray technology is emerging which will enable high contrast imaging of the pure living state on an atomic scale, a microvisualization of biological materials impossible to achieve by any other known means. The goal of the proposed program is the development of the technology and instrumentation needed for the application of x-ray biological microholograms to living matter. The approach used involves the use of ultrahigh brightness ultraviolet lasers as the technical means for producing the needed short wavelength radiation. The instrumentation required to control the ultraviolet energy features as the focus of this program.

*Includes no-cost extension.

21. THE MAGNETICALLY INSULATED INERTIAL CONFINEMENT FUSION (MICF)-A NOVEL APPROACH

UNIVERSITY OF MICHIGAN
Ann Arbor, Michigan 48109-2104

T. Kammash
Department of Nuclear Engineering

Date Started: June 1, 1987

$89,000

Anticipated Duration: 3 years

The objective of this project is to study the relevant physics issues that bear directly on the potential of the Magnetically Insulated Inertial Confinement Fusion (MICF) concept as a power-producing reactor. In this novel approach the favorable aspects of both magnetic and inertial fusions are utilized in that the hot, dense, fusion grade plasma is physically contained by a metallic shell while its heat is insulated by a strong, self-generated magnetic field. Experimental studies at Osaka University using 100 Joule, CO_2 laser impinging on a target of parylene shell of few milimeters in radius have resulted in a Lawson parameter (product of density and confinement time) of $5x10^{12}$ sec cm^{-3} at a plasma temperature of 0.5 keV. In contrast to implosion type inertial confinement schemes the MICF approach allows for the creation of the desired plasma within a shell by means of laser radiation that enters through a hole in the shell and strikes the fuel-coated inner surface. The return currents generated by the energetic ablated electrons give rise to the strong magnetic field that provides the desired thermal insulation. Because of this unique arrangement the lifetime of the burning plasma will be significantly higher than in conventional implosion type inertial fusion and the energy efficiency will be superior since the input laser energy is put directly into the plasma. It is therefore expected that the ignition conditions will be much less severe, and the energy multiplication will be much larger than in the conventional counterpart and this project is aimed at verifying these properties and how they impact the reactor aspects of this concept.

22. APPLICATION OF HIGH POWER MODULATED INTENSE RELATIVISTIC ELECTRON BEAMS FOR DEVELOPMENT OF A WAKE FIELD ACCELERATOR

NAVAL RESEARCH LABORATORY
Washington, D.C. 20375-5000

Moshe Friedman

Date Started: August 1, 1986

$336,000

Anticipated Duration: 3 years

Future progress in accelerators and their applications depend critically on the development of new mechanisms capable of generating high voltage gradients. The objective of this program is to show that high electric fields can be established in a structure by the wake field of a modulated intense relativistic electron beam (MIREB) propagating through the structure. The simplicity and high efficiency of generating MIREBs with power $\gtrsim 10^{10}$ watts by an external low power RF source suggests advantages of a wake field accelerator over a more conventional approach to generating high currents of high energy particles. It is anticipated that at the end of the project, proof-of-principle results demonstrating particle acceleration through a voltage gradient $\gtrsim$100 MV/m will be at hand with scaling laws needed to design practical devices for future applications.

23. *THE CHIRPED-PULSE FREE-ELECTRON LASER

UNIVERSITY OF NEW MEXICO
800 Yale Blvd., N.E.
Albuquerque, New Mexico 87131

Gerald T. Moore
Center for Advanced Studies

Date Started: September 1, 1987

$95,000

Anticipated Duration: 1 year

A theoretical and numerical investigation is made of pulsed free-electron lasers in which there is a dependence of the electron energy on the time of injection into the wiggler. Such devices are expected to produce coherent optical pulses whose frequency varies (chirps) over the pulse length by a large amount. Such pulses have never before been produced, and should have a number of applications. Chirping should produce enhanced efficiency in the high-power regime, where the electrons become trapped by the fields and slowed down. Combining chirping with tapering of the wiggler wavelength or magnetic field may also lead to a new type of electron accelerator in which energy is transferred from slower electrons to faster electrons via the laser field.

*Project completed.

24. REDUCTION IN ENERGY AND OPERATING COSTS FOR ENZYMATIC CELLULOSE HYDROLYSIS BY A NOVEL METHOD FOR ENZYME RECOVERY

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831

Charles D. Scott
Chemical Technology Division

Date Started: July 1, 1986

$175,000

Anticipated Duration: 3 years

The objective of this program is to significantly reduce the costs associated with enzymatic cellulose hydrolysis for the production of high energy fuels and chemicals by demonstrating the feasibility of a novel method for the recovery of the enzyme cellulase from aqueous solutions and from undigested cellulosic residues. The method is based upon the ability of specific absorbent molecules to either "mop" up cellulase from solution or to effect the desorption of cellulase from the residues. Subsequent release of cellulase from the absorbents will allow reuse of the enzyme. For example, cellulase absorbed onto inorganic kieselguhr granules coated with concanavalin A desorbs from this support when contacted with cellulose. The work will be divided into three categories: (1) identification of appropriate support materials with affinity for cellulase, (2) determination of the effect of fuels and chemicals (fermentation products) on the affinity of appropriate supports for cellulase, and (3) design and development of suitable reactor systems for enzymatic cellulose hydrolysis with enzyme recovery.

25. *RESEARCH ON X-RAY OPTICS WITH THE ULTIMATE AIM OF PRODUCING A SYNCHROTRON RADIATION PUMPED SOFT X-RAY LASER

UNIVERSITY OF OREGON
Eugene, Oregon 97403

Paul L. Csonka
Institute of Theoretical Science

Date Started: January 1, 1985

$121,000

Anticipated Duration: 44 months**

The immediate goal of the project is to achieve significant improvements in the areas of synchrotron radiation focusing, pulse shaping and the development of new types of radiation energy filters. These results are expected to lead to superior x-ray imaging, higher radiation brilliance, better spectral and time resolution for a variety of experiments with a wide field of applications, including materials science, solid state physics and biology. Furthermore, these developments are designed so as to ultimately permit construction of a soft x-ray Li laser pumped with synchrotron radiation, with a repetition rate which cannot be matched by other methods.

*Project completed.
**Includes no cost extension.

26. HOLOGRAPHIC RUGATE STRUCTURE FOR X-RAY OPTICS APPLICATION

PHYSICAL OPTICS CORPORATION
3305 Dow Avenue
Redondo Beach, California 90278

Joanna Jannson
Optics Lab

Date Started: September 25, 1986

$234,000

Anticipated Duration: 38 months*

A new approach to x-ray optics fabrication is based on the single-step holographic fabrication of highly-efficient x-ray dispersion elements, as well as imaging optics, gratings, lenses and mirrors. In this investigation, the holographic recording of interference patterns produced by two coherent electromagnetic waves is used to create the desired transmission and reflection Bragg holographic structures in the soft x-ray region of less than 30 nm. For applications involving grazing incidence, an argon laser can suffice as a recording coherent source, while for generating normal incidence optics, x-ray laser radiation will be used to create the large number of Bragg multilayers (>1000). Unlike conventionally deposited multilayer films, these Bragg structures are quasi-sinusoidal in composition and thus eliminate the problems with discrete interfaces. As a result, such holographic optics possess superior mechanical and laser damage properties, higher operating efficiency, and is potentially more economical to be mass-produced.

*Includes no cost extension.

27. THIN-FILM COMPOSITE MEMBRANES FOR ARTIFICIAL PHOTOSYNTHESIS

PORTLAND STATE UNIVERSITY
Portland, Oregon 97207

Carl C. Wamser

Date Started: July 15, 1985

$231,000

Anticipated Duration: 3-1/2 years*

The objective of this program is to develop polymeric membranes which will be useful for photosensitization of separate oxidation and reduction reactions on opposite sides of the membrane. Ultimately these redox reactions will be coupled to the oxidation and reduction of water or other energy-storing reactions. Membranes will be optimized with respect to the following characteristics: a) absorption of the solar spectrum, b) photoinduced electron transport across the membrane, c) photosensitization of appropriate redox reactions at the membrane surfaces, d) durability, and e) economic considerations.

*Includes no cost extension.

28. STUDY OF THE FEASIBILITY OF X-RAY LASING ACTION IN A CONFINED PLASMA COLUMN USING A POWERFUL PICOSECOND LASER

PRINCETON UNIVERSITY
P.O. Box 451
Princeton, New Jersey 08544

Szymon Suckewer
Plasma Physics Laboratory

Date Started: January 1, 1985

$1,183,000

Anticipated Duration: 6 years

The main goal of this project is the experimental investigation of methods, based on a powerful picosecond laser (PP-laser), for obtaining high gain and lasing action, initially in the spectral region 100-200 Å, as well as the study of possibilities for creating a high gain at shorter wavelengths in the region of 60-70 Å. Theoretical modeling of obtained results should make it possible to predict conditions for lasing action at 10-20 Å using the same experimental method. The basic idea is to provide interaction of a PP-laser with a confined plasma column by resonance multiphoton excitation of ions in order to obtain, in a short time, a large population inversion in multi-electron high-Z ions as well as in H- and Li-like ions of low-Z elements (low-Z elements are considered here for picosecond laser powers significantly exceeding 10^{15} W/cm^2). The interaction of the PP-laser with a plasma column, which is created by a CO_2 laser, distinguishes this project from studies of the interaction of a PP-laser with cold gas or solid targets. Ions at the proper state of ionization will be created independently in the plasma, and the role of the PP-laser will be reduced to providing a high population inversion. Such a plasma column has favorable conditions for population inversion and gain even without a picosecond laser pulse due to fast radiation. The experimental program has three stages: (i) the design and construction of the PP-laser based on KrF* excimer laser, (ii) study of the interaction of the PP-laser radiation with ions in a recombining plasma column by photo-ionization and multiphoton ionization, and (iii) creation of a strong population inversion (high gain) in multi-electron ions by multiphoton excitation.

29. SOFT X-RAY LASER MICROSCOPE

PRINCETON X-RAY LASER
P.O. Box 3526
Princeton, New Jersey 08540

Szymon Suckewer

Date Started: September 1, 1986

$288,000

Anticipated Duration: 38 months*

The objective of this project is to design and construct a Soft X-ray Laser Microscope which will be incorporated into the Soft X-ray Laser Experiment presently operating at a wavelength of 182 Å at Princeton University. This design will also have a provision to adapt the microscope to a new system involving a Soft X-ray Laser significantly below 100 Å, with very short pulses (1 - 10 ps), currently under study at Princeton University. Therefore, the uniqueness of the Soft X-ray Microscope design will be in the application of coherent radiation from a soft x-ray laser.

*Includes no cost extension.

30. ELECTROCATALYTIC HYDROCRACKING

RESEARCH TRIANGLE INSTITUTE
P. O. Box 12194
Research Triangle Park, NC 27709

Donald R. van der Vaart
Center for Process Research

Date Started: February 15, 1988

$124,000

Anticipated Duration: 3 years

Conventional hydrocrackers rely on extremely high hydrogen partial pressures (>1500 psi) both to facilitate hydrogenation and reduce coke formation on the catalyst surface. In an electrochemical cell using a proton selective solid electrolyte, protons formed on the counter electrode can, as charge carriers, be transported through the electrolyte to the surface of the working electrode which is exposed to the liquid hydrocarbon at ambient pressure. The dual functionality required of hydrocracking catalysts is provided by this hydrogenating/ dehydrogenating (metal) site and the cracking sites of the solid electrolyte. The ready supply of hydrogen delivered directly to the reaction interface should limit coke formation and, hence, greatly reduce the operating pressure requirements. This decrease in the rate of surface deactivation would enable lower quality (heavier) feeds to be (electrocatalytically) hydrocracked to produce gasoline and middle distillates at significantly lower costs.

31. INVESTIGATION OF PARAMETERS CRITICAL TO MUON-CATALYZED FUSION

S&J SCIENTIFIC COMPANY
P. O. Box 7070
University Station
Provo, Utah 84602

Steven E. Jones

Date Started: September 1, 1987

$235,000

Anticipated Duration: 27 months

It has been demonstrated (in conjunction with others on the program) that muon catalysis cycling rates increase rapidly with increasing deuterium-tritium gas temperatures and densities. Furthermore, muon-capture losses are significantly smaller than predicted before the experiments began. As a result of these effects, muon-catalyzed fusion yields of 150 fusions/muon (average) have been achieved. The fusion energy thereby released, nearly 3 GeV/muon, significantly exceeds theoretical expectations, and still higher yields are expected. Therefore, it is proposed to explore the limits of muon-catalyzed fusion, to provide answers to questions regarding energy applications of muon-catalyzed fusion.

32. GAS JET DEPOSITION OF METALLIC, SEMICONDUCTING AND INSULATING FILMS

SCHMITT TECHNOLOGY ASSOCIATES
25 Science Park
New Haven, Connecticut 06511

Bret Halpern

Date Started: November 15, 1987

$183,000

Anticipated Duration: 3 years

Gas Jet Deposition (GJD) is a new method for depositing thin films at high rate and controlled energy. The basic physics of GJD will be investigated in order to develop its technological capabilities. GJD deposits films by "seeding" atoms or molecules into a free jet expansion, e.g., of helium, and directing the jet at a substrate at relatively high pressure. GJD promises many advantages over established methods. Deposition rates of 10 microns per minute have been attained, and microns per second should be within range. The impact energy of depositing species can be gasdynamically controlled over a range of electron volts, so that film properties can be influenced during deposition. The substrate, which can be almost any material, can remain cool during deposition. Film composition and doping profile can be easily varied. Clusters can be deposited as well as atoms and molecules. GJD is flexible, and any metal, semiconductor, or insulator that can be seeded in the free jet can be deposited. The combination of these features in one method makes GJD singularly versatile. The goal of this project is to explore the feasibility of GJD as the basis of a usable technology. To do this, the fundamentals of GJD will be investigated, in particular its high rate and impact energy control, and the GJD apparatus will be refined. The properties of the films produced will be determined.

33. MAGNETICALLY INSULATED IMPACT FUSION

SCIENCE APPLICATIONS INTERNATIONAL CORP.
206 Wild Basin Road, Suite 103
Austin, Texas 78746

Daniel C. Barnes

Date Started: May 1, 1987

$199,000

Anticipated Duration: 1-1/2 years

This theoretical study will develop and investigate a concept for combining magnetic insulation of particle energy with impact driven compression of thermonuclear fusion targets. A novel approach to formation of a wall-confined spheromak inside an imploding metallic liner is considered. The resulting system is expected to achieve a few hundred times inertial energy confinement. Thus, in contrast to uninsulated impact fusion targets, present or near-term electromagnetic launch technology could deliver the impact of 10-20 km/s required to produce significant thermonuclear yield. Energy confinement, target preparation, and shell hydrodynamics will be investigated. Experimentally relevant target designs will be developed and analyzed.

34. *FOCUSED SHOCK DRILLING EXPLORATORY RESEARCH PROGRAM

TETRA CORPORATION
4905 Hawkins NE
Albuquerque, New Mexico 87109

William M. Moeny

Date Started: March 1, 1985

$278,000

Anticipated Duration: 38 months**

The objective of this program is to determine the feasibility of the high energy focused shock drill as a new approach to drilling oil or gas wells. This technology utilizes electrical sparks in water to fracture rock, taking advantage of recent advances in pulse power technology. This program is to construct a proof of principle focused shock drill and demonstrate rock cutting characteristics at very high energy and power levels. This machine has greater than a ten fold energy increase and 10 to 100 fold pulse power increase over previous spark drilling schemes. The characteristics of focused shock drilling were determined as a function of energy deposition and peak power; also studied were the impulse transmitted to the rock, rock fracture rate, and the steerability of the drill.

*Project completed
**Includes no cost extension.

35. AERODYNAMIC FOCUSING OF PARTICLES AND HEAVY MOLECULES

YALE UNIVERSITY
P. O. Box 2159
Yale Station
New Haven, Connecticut 06520-2159

Juan Fernandez de la Mora
Department of Mechanical Engineering

Date Started: July 1, 1987

$70,000

Anticipated Duration: 2 years

Theoretical predictions indicate that, by accelerating a gas-particle mixture through a converging nozzle, it is possible to concentrate dense beams of small uncharged particles into a narrow focus under previously unexplored conditions. Because high resolution aerodynamic focusing could be exploited in a variety of applications, including "direct writing," basic studies are proposed in order to assess its limits and potential technological impact. Experiments with micron-size aerosol particles (for which Brownian motion effects are negligible) will first examine the ratio between the diameters of the nozzle exit and the focal region size, for which theory predicts values well in excess of 100. These studies will be subsequently extended down to the molecular level, by substituting the suspended particles with neutral vapors of a heavy species (Au,WF_6, etc.) diluted in gaseous H_2 or He. The non-negligible Brownian motion of the heavy component leads then to a finite diffusive broadening of the focal region and sets a limit to the writing resolution attainable. Two theoretical approaches are proposed to study this defocusing phenomenon, one based on Brownian-dynamics simulations and the other exploiting the smallness of the random velocity as compared with the mean velocity of the heavy molecules. The phenomenon will also be studied experimentally, first visually by laser-induced fluorescence (LIF) of I_2 molecules seeded in high-speed jets of H_2 and He and also by sampling from He-Hg jets through a small orifice in a plate and analyzing for the concentration of Hg.

SAMPLE

Statement of Work

1) Project Objective

The proposer shall investigate the electrocatalytic oxidative dehydrogenation of ethylbenzene and butane in solid electrolyte fuel cells. The effort is directed toward defining optimal operating conditions for achieving high yields of styrene and butadiene with simultaneous electric energy generation.

2) The work to be performed consists of the following tasks:

   2.1. Construction of tubular stabilized zirconia fuel cells with a platinum cathode and an iron oxide or platinum anode. Both anode materials are quite promising and a decision between the two will be made after preliminary runs.

   2.2. Measurement of the styrene cell activity and yield as a function of temperature, inlet ethylbenzene concentration and external resistive load.

   2.3. Measurement of the cell electric power output and overpotential as a function of the operating parameters described in 2.2.

   2.4. Determination of the nature of the overpotential according to the results of 2.3. If ohmic overpotential dominates, a small well mixed cell with thin (150 microns) electrolyte discs will be constructed to increase power density.

   2.5. Development of correlation for styrene yield and electrical power output in terms of operating and design parameters for use in future scale up.

   2.6. Repeat tasks 2.2. through 2.5. using butane and/or butene as the fuel.

   2.7. Preliminary engineering and economic analysis according to the results of 2.2. through 2.6.

3) Deliverables

The proposer shall provide the data of experiments performed according to paragraphs 2.2., 2.3., 2.4., 2.5. and 2.6. along with analyses and conclusions based on this data.

4) Performance Schedule

   4.1. Complete construction of cells 3 months after start of work.

   4.2. Complete ethylbenzene experiments within 12 months after start of work.

   4.3. Complete butane and butene experiments and data analysis 20 months after start of work.

   4.4. Complete data correlation, economic analysis and final report 24 months after start of work.

OFFICE OF BASIC ENERGY SCIENCES

DIVISION OF ADVANCED ENERGY PROJECTS

Fiscal Year 1988 Program Data
(does not include HIFAR or SBIR data)

FY '88 Budget

Operating Funds....................$9,039,000

Capital Equipment Funds............$ 128,000

Distribution of Projects by Institutional Sector

Universities	37%
Small Business	17%
Other Industry	9%
DOE Laboratories	34%
Federal Laboratories	3%

The Division of Advanced Energy Projects also manages the Heavy Ion Fusion Accelerator Research (HIFAR) program. In this program, research and development is performed on the heavy-ion induction linear accelerator method to assess its suitability as a "driver" for electric power plants based on the principle of inertial confinement fusion. HIFAR addresses the generation of high-power, high-brightness beams of heavy ions, the understanding of scaling laws in this novel physics regime, and the validation of new accelerator strategies for reducing costs. The program strategy is to attack these issues in a sequence of experiments of increasing scale. The present HIFAR experimental capability represents the early stages of this sequence. The four beam experiment, MBE-4, now under way following completion of the apparatus in FY 1987, models longitudinal beam control and acceleration in the electrically focused portion of a driver. An ion injector is being built to explore physics and technology issues associated with the generation of as many as sixteen 500 mA beams of C^+ ions accelerated to 2 MeV.

In FY 1988, the HIFAR budget was $5,261,000 in operating funds and $847,000 in capital equipment funds. The majority of the HIFAR effort is being performed at the Lawrence Berkeley Laboratory. Supporting research on specific HIFAR program elements is under way at the Lawrence Livermore National Laboratory, the Stanford Linear Accelerator Center, and the Naval Research Laboratory.

Also, AEP manages a number of projects in the Small Business Innovation Research (SBIR) program. These projects are shown on pages 26 to 32.

In Fiscal Year 1988 the Division of Advanced Energy Projects managed 13 Phase I projects. The goal of Phase I projects is to determine the feasiblity of the proposed concept. The projects were selected from proposals submitted to the Advanced Energy Projects topic, "High Temperature Superconducting Materials: Processing and Devices," which was included in the 1988 DOE SBIR Program Solicitation. The principal investigator is identified below the project title. The total funding for each Phase I project is shown.

36. INFRARED DETECTORS USING HIGH CRITICAL TEMPERATURE GRANULAR JOSEPHSON JUNCTIONS

David G. Hamblen

$49,877

ADVANCED FUEL RESEARCH, INC.
87 Church Street
East Hartford, Connecticut 06108

Date Started: July 25, 1988

Anticipated Duration: 6-1/2 months

The recent discovery of high temperature superconducting materials has led to renewed interest in the application of superconductivity. The new ceramic superconductors offer the opportunity of using these materials as detectors of infrared radiation more conveniently that the older, classical superconductors. The larger energy gap of these new high critical temperature (T_c) materials also provides the opportunity to fabricate Josephson junction (JJ) detectors capable of sensing radiation at much shorter wavelengths, offering new competition to previous semiconductor IR detectors in the 10 to 100 μm region. Recent work has demonstrated that granular superconductors show wide-band sensitivity to radiation. The objective of the present project is to use the new technology in making thin films of these granular superconductors to develop IR sensors based on these effects. The approach in Phase I is to use films of the YBaCuO and BiCuBaSr materials (and possibily others) to demonstrate the feasibility of these materials as IR detectors.

37. EXTRUSION OF HIGH TEMPERATURE SUPERCONDUCTING MATERIALS

ATEK METALS CENTER, INC.
10052 Commerce Park Drive
Cincinnati, Ohio 45246

James C. Hunt

Date Started: July 25, 1988

$48,884

Anticipated Duration: 6-1/2 months

Initial trials have shown that the high pressure, elevated temperature extrusion process is useful for converting the $YBa_2Cu_3O_{7-x}$ (123) superconducting oxide into dense shapes. Although this process is commonly used in the metalworking industry, it is not commonly used for ceramic extrusion. By introducing a thick, ductile, metallic, outer enclosure it is possible to obtain ductile behavior from a brittle material inside the billet: the 123 superconducting oxide. Since the extrusion process relies on deformation at elevated temperature, the desired orthorhombic structure may be transformed to the unwanted tetragonal structure. To limit this transformation, extrusions will be performed in this project using controlled temperature and pressure conditions in the presence of oxygen.

38. FABRICATION AND PROCESSING OF HIGH TEMPERATURE SUPERCONDUCTING MATERIALS

CAPE COD RESEARCH
P. O. Box 600
Buzzards Bay, Massachusetts 02532

Gregory D'Andrea

Date Started: July 25, 1988

$50,000

Anticipated Duration: 6-1/2 months

High critical temperature superconducting ceramics hold promise for numerous applications in energy storage, communications and sensing technologies. However, technical problems associated with the fabrication and processing of these materials must first be overcome. This research project applies electrochemical deposition to the problems of processing thallium group superconducting ceramics containing non-rare earth elements. If successful, these nonaqueous techniques could quickly take developments in ceramic superconductors from the laboratory to the marketplace.

39. DEVELOPMENT OF MULTIFILAMENTARY SUPERCONDUCTING COMPOSITES

EIC LABORATORIES, INC.
111 Downey Street
Norwood, Massachusetts 02062

Stuart F. Cogan

Date Started: July 25, 1988

$50,000

Anticipated Duration: 6-1/2 months

This project will develop multifilamentary $YBa_2Cu_3O_{7-x}$ (123) superconducting composites. The fabrication process is based on the sol-gel preparation of continuous-filament 123 material by a melt spinning technique followed by liquid metal infiltration of multifilament bundles to form a cryostabilized superconducting composite. The important issues for high critical temperature (T_c) superconductors in high current applications are the crystallographic orientation dependence of critical current density (J_c), superconductivity across grain boundaries, magnetic field dependence of J_c, and the stabilization requirements of the superconducting state. The sol-gel process addresses these issues through the use of crystallographic texturing developed from molecular level sol chemistry, the preparation of the superconductor as cryostable fine filaments, and the use of high electrical and thermal conductivity normal state metal matrices. The overall project objective is the fabrication of a multifilamentary superconducting composite comprised of 123 filaments in an aluminum matrix.

40. FABRICATION OF HIGH TEMPERATURE SUPERCONDUCTOR FILAMENTS FROM METAL-CONTAINING POLYMERIC PRECURSORS

FIBERTEK, INC.
510-A Herndon Parkway
Herndon, Virginia 22070-5225

German de la Fuente

Date Started: July 25, 1988

$49,028

Anticipated Duration: 6-1/2 months

The use of metal-containing polymers as precursors to high critical temperature (T_c) superconducting filaments will be explored through a proprietary low-temperature solution synthesis. Careful evaluation of the pertinent chemical literature will be done to optimize the starting material combination and to help determine adequate experimental conditions that will yield a homogeneous, polymeric precursor with the expected Ba-Y-Cu composition ratio. Appropriate firing and oxygen annealing processing cycles will be determined subsequently in order to obtain dense, homogeneous, fully reacted $YBa_2Cu_3O_{7-x}$ superconducting filaments of greater quality than currently available from conventional processing techniques. In order to achieve a degree of understanding of the process, as well as to optimize it, several characterization techniques will be applied. These include solution spectroscopy methods, such as infrared, nuclear magnetic resonance, and ultraviolet/visible methods; contactless methods to determine T_c, current density, and magnetic properties; and x-ray diffraction and scanning electron microscopy to determine the number and purity of the phases present, as well as to characterize the sample microstructure. Mechanical properties and integrity of the high T_c filaments produced will be measured to help determine whether the materials will meet the necessary criteria for their ultimate application into practical devices.

41. A NOVEL OXYGEN - PLASMA-SPRAY SYSTEM FOR THE PROCESSING OF HIGH TEMPERATURE SUPERCONDUCTORS

FLAME-SPRAY INDUSTRIES, INC.
152 Haven Avenue
Port Washington, New York 11050

Daniel R. Marantz

Date Started: July 25, 1988

$49,775

Anticipated Duration: 6-1/2 months

Plasma spray deposition technology can be used to process coatings and free-standing forms of high temperature superconducting oxides. While this versatile technique holds high potential, it nonetheless has deficiencies, since the coating as sprayed does not display a superconducting transition but, rather, must be subjected to a relatively high temperature anneal to replace the oxygen that was lost during the plasma spray process. This post-spray anneal complicates the fabrication process and severely limits the substrate material that can be employed to fabricate a device. In this project a plasma spray device will be developed that can operate with an oxygen plasma. With conventional plasma guns this is not possible because an oxygen-bearing plasma would destroy the electrodes. Using a specially configured plasma gun, capable of establishing an oxygen-rich plasma environment, this project will form as-sprayed deposits having the proper oxygen content to enable high critical temperature (T_c) behavior. No post-spray anneal would be required, which will permit the coating of a wide range of substrate materials.

42. AN ORIENTED HIGH TEMPERATUREOR SUPERCONDUCTOR FABRICATED BY A NOVEL TECHNIQUE FOR USE IN POWER APPLICATIONS AT LIQUID NITROGEN TEMPERATURE

INTERMAGNETICS GENERAL CORPORATION
1875 Thomaston Avenue
Waterbury, Connecticut 06704

Leszek R. Motowidlo

Date Started: July 25, 1988

$49,894

Anticipated Duration: 6-1/2 months

The recent announcement of superconductors with critical temperature above liquid nitrogen is expected to greatly expand the potential applications for superconductors. To be technically and commercially useful for power applications, these materials will have to be incorporated into wire or tape form. The efforts of this research will focus on innovative design and fabrication methods for a high temperature $YBa_2Cu_3O_{7-x}$ (123) superconductor process for wires and/or tapes. Demonstration of key components of fabrication will also be undertaken on small samples.

43. ENHANCEMENT OF CRITICAL CURRENT DENSITY IN HIGH TEMPERATURE SUPERCONDUCTING CERAMIC WIRE THROUGH HOT-EXTRUSION INDUCED TEXTURE

JUPITER TECHNOLOGIES, INC.
187 Langmuir Laboratory
Brown Road
Ithaca, New York 14850

Prakash C. Panda

Date Started: July 25, 1988

$50,000

Anticipated Duration: 6-1/2 months

This project will investigate the feasibility of obtaining useful texture in high critical temperature (T_c) $YBa_2Cu_3O_{7-x}$ superconducting compounds through isothermal hot extrusion of fine grain powder compacts in the form of a dense wire. The critical temperature and the critical current density will be measured and correlated with the texture of the wires. The information will be assembled in the form of a processing map where the extrusion reduction ratio and the strain rate are represented as the axes; and in the map the regime where satisfactory critical current density is obtained will be separated from the regime where the critical current density is inadequate. The goal of this research is to fabricate wires of the superconducting ceramic with a current carrying capability of $10^5 A/cm^2$ at zero resistance and temperatures above that of liquid nitrogen.

44. MAGNETIC CONTROL OF CRITICAL CURRENTS IN SUPERCONDUCTING QUANTUM INTERFERENCE DEVICES OPERATING AT 77 K

PHYSICAL DYNAMICS, INC.
P. O. Box 1883
La Jolla, Callifornia 92038

Walter N. Podney

Date Started: July 25, 1988

$49,851

Anticipated Duration: 6-1/2 months

The SQUID (Superconducting Quantum Interference Device) makes possible magnetic measurements of unequalled sensitivity. Heretofore, practical SQUID systems have been cooled by liquid helium. The problem of reliably fabricating practical, low noise SQUIDs that operate in liquid nitrogen remains unsolved. The extremely short coherence length in the high critical temperature superconductors (about 20 angstrom) makes fabrication of weak links from multi-layer thin films unreliable. Thin film SQUIDs made thus far operate noisily at 77 K. SQUIDs made by forming crack junctions in bulk rings of superconducting material operate with low noise but are too fragile for practical application. This project involves a novel approach to the manufacture of SQUIDs that can operate reliably and with low noise in liquid nitrogen. Weak links in the single layers or bulk forms of the oxide superconductor are made in two steps. First, a physical constriction is made to attain a critical current of a few milliamperes. Next, the critical current is reduced to the target value of a few microamperes magnetically, using the properties of oxide superconductor grain boundaries. Phase I of this project will demonstrate the feasibility of magnetically controlling the critical current in a weak link in bulk oxide. The demonstration will clear one of the major obstacles on the path to production of practical SQUID systems operating in liquid nitrogen.

45. A NEW AND NOVEL TECHNIQUE FOR THE SPUTTER DEPOSITION OF HIGH TEMPERATURE SUPERCONDUCTING THIN FILMS AND COATINGS

PLASMA AND MATERIALS TECHNOLOGIES, INC.
222 West Orange Grove Avenue
Burbank, California 91502

Gregor Campbell

Date Started: July 25, 1988

$49,944

Anticipated Duration: 6-1/2 months

A unique procedure has been developed for the reactive sputter deposition of thin films. The approach has proved superior to that of magnetrons, giving better process control and film quality, and the possibility for higher deposition rate. A novel approach for the deposition of high temperature superconducting (HTS) thin films involves producing one or multiple plasma beams and transporting the plasma along a weak guide magnetic field to separate targets of Y, Ba and Cu located at a distance up to 1 m from the plasma source. The current to the target is controlled by adjusting the plasma power while the sputter rate from each target is controlled individually through adjusting the target voltage. The procedure offers a number of key advantages including control over the stoichiometry of the films. The separation of plasma production and sputter deposition gives process stability by preventing oxidation of the targets. This project will demonstrate this unique plasma sputtering arrangement for producing HTS films, with special control over the stoichiometry of the films and the rate of film production. Superconducting thin films will be deposited on strontium titanate substrates and their superconducting properties will be measured.

46. THE PREPARATION OF THIN FILM SUPERCONDUCTORS BY CHEMICAL VAPOR DEPOSITION OF VOLATILE METAL CHELATES

SIEVERS RESEARCH, INC.
1930 Central Avenue, Suite C
Boulder, Colorado 80301

Richard Hutte

Date Started: July 25, 1988

$49,970

Anticipated Duration: 6-1/2 months

A novel technique for the preparation of thin films of the rare earth/barium/copper oxide superconductors is under development in this project. Volatile fluorinated beta-diketonate metal chelates of Eu, Yb, Ba, and Cu will be synthesized and thin films of mixed metal oxides, e.g., $EuBa_2Cu_3O_7$, will be prepared on a suitable substrate by chemical vapor deposition of the metals in the presence of oxygen. It is anticipated that this approach to the formation of thin films of superconducting materials will offer many advantages over the sputtering techniques currently employed, including formation of the high critical temperature (T_c) materials at lower temperatures, and better control of film thickness and composition. The use of metal complexes prepared from fluorinated beta-diketones could also lead to the development of new superconducting materials.

47. ENHANCEMENT OF TRANSPORT CURRENT DENSITY IN $YBa_2Cu_3O_{7-x}$ SUPERCONDUCTORS USING DUAL-TEMPERATURE EXTRUSION PROCESSING

SUPERCON, INC.
830 Boston Turnpike
Shrewsbury, Massachusetts 01545

Donald W. Capone

Date Started: July 25, 1988

$49,993

Anticipated Duration: 6-1/2 months

Tremendous excitement and interest has been generated in recent months over the discovery of the $YBa_2Cu_3O_{7-x}$ (123) liquid nitrogen superconductors. However, this excitement has been tempered by the inability to achieve large transport current densities (J_cs) in bulk-processed polycrystalline materials because of weak-link behavior. These weak-links have two possible origins; firstly, the presence of non-superconducting phases at the grain boundaries and, secondly, the intrinsic anisotropy of the superconductivity in the high critical temperature superconductors. In this project the 123 powders will be processed avoiding the presence of a non-superconducting $BaCuO_2$-CuO eutectic, with a melting temperature of about 900°C, and dual-temperature extrusion techniques will be used to cold work and densify the powders. Initial experiments show encouraging results, giving ceramic fibers with 90% green density.

48. ENHANCEMENT OF TRANSPORT CURRENT DENSITY IN $YBa_2Cu_3O_{7-x}$ SUPERCONDUCTORS USING LOW TEMPERATURE DENSIFICATION

SUPERCON, INC.
830 Boston Turnpike
Shrewsbury, Massachusetts 01545

Donald W. Capone

Date Started: July 25, 1988

$50,000

Anticipated Duration: 6-1/2 months

The discovery of the $YBa_2Cu_3O_{7-x}$ (123) superconductors with a critical temperature (T_c) well above liquid nitrogen temperatures brought the level of interest and excitement in superconductivity to unprecedented heights. Unfortunately, the transport current density (J_c) of this material, especially in bulk-processed polycrystalline powders, is not high enough. This is believed to be due to weak-link behavior. These weak-links have two possible origins: firstly, the presence of non-superconducting phases at the grain boundaries and, secondly, the intrinsic anisotropy of the superconductivity in the high T_c superconductors. In this research project the effects of low temperature densification processes on the transport critical currents in 123 superconducting composites will be studied. The low temperature densification processes, room temperature swaging, and room temperature rolling, will allow avoidance of the presence of a non-superconducting $BaCuO_2$-CuO eutectic, with a melting temperature of approximately 900°C. Also, the cold work in these processes will densify and texture the powders. Initial experiments show encouraging results, giving ceramic fibers with 90% green density.

INVESTIGATOR INDEX
(Project Numbers)

INSTITUTIONAL INDEX
(Project Numbers)