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SCHOLARLY RESEARCH IN AEROSPACE POWER

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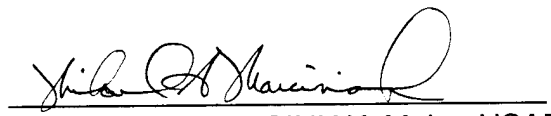

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13. ABSTRACT *(Maximum 200 words)*

This final report summarizes the efforts of Air Force contract F33615-81-C-2013 entitled "Scholarly Research In Aerospace Power" administered by Dr. Jay Pinson, School of Engineering, San Jose State University, accomplished under the contract. Each task identifies the principal investigator and includes objective, conclusions and recommendations.

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TASK #1

TITLE: CORROSION RATES OF Ni-Co ALLOYS AND PROPERTIES OF THE CORROSION FILM

PRINCIPAL INVESTIGATOR: DR. JOHN J. LANDER (INDEPENDENT CONTRACTOR)

The task objective was to eliminate or substantially reduce the deleterious effects of "memory" on cold, high rate discharge performance of nickel plates by incorporation of cobalt in the plaque corrosion layer.

Because of the wide use of nickel-cadmium batteries, the corrosion rates of nickel and nickel-cobalt alloys are of interest to nickel-cadmium battery electrochemical theory and its technology. The nickel plaque component of the nickel plate is known to corrode and become an electrochemical part of the active material, NiO(OH). Such corrosion serves to weaken the plaque structure supporting the active material and contributes to degradation of its mechanical stability and, possibly, increases its electrical resistance due to the formation of a high resistivity film between the active material and the nickel metal of the plaque. Additionally, in sealed Ni-Cd cells, the corrosion results in using up the reserve $Cd(OH)_2$ at the negative plate, rendering the cell liable to failure via H_2 gas production on overcharge. The addition of cobalt to the active material of the nickel electrode has the beneficial effect of markedly improving charge acceptance (efficiency) of the nickel electrode, especially at the elevated temperatures.

In particular, the plaque material of the cathode consists of a Ni-Co alloy in solid solution wherein the cobalt is by weight one to ten percent of the alloy. Conventional methods of applying the plaque material to the nickel core may be used.

TASK #1 (Continued)

It is therefore possible to provide an improved cathode for a nickel-cadmium battery wherein the nickel corrosion is substantially lessened in the plaque material.

TASK #2

TITLE: THEORETICAL ANALYSIS OF THE TEMPERATURE DEPENDENCE OF BANDGAP AND IMPURITY-BAND CHARACTERISTICS IN SEMICONDUCTOR MATERIALS

PRINCIPAL INVESTIGATOR: DR. L. CARLTON BROWN (OHIO STATE UNIVERSITY)

The objective of the study was to develop a working model/description for the variation with temperature of impurity band formation in semiconductors using a combined screened potential and statistical variation of nearest neighbor interactions.

The effort considers a combination of screened potential and statistical variation of nearest neighbor interactions to develop a model consistent with impurity-band conduction and band gap narrowing data in semiconductor materials. The combined effects indicate that a semiconductor-to-metal transition occurs at impurity concentrations lower than with either of the effects taken separately and that local regions of conductivity occur at even lower concentrations. Furthermore, the model indicates that the band gap energy, E_G, decreases with increasing concentration in a manner similar to that of a corresponding decrease of donor (acceptor) binding energy. In addition, the study indicates that a fringe or "tail" forms on the low energy side of the donor level density of states as well as on the low energy edge of the conduction band. As concentration is increased, this "tail" formation extends well into the energy gap.

TASK #3

TITLE: THERMIONIC REACTOR POWER SYSTEM STUDY

PRINCIPAL INVESTIGATOR: G. FITZPATRICK (RASOR ASSOCIATES)

The objective of this effort was to compare the performance merits of a thermionic reactor and the baseline SPAR thermoelectric reactor using consistent assumptions. An assessment of design risk, life and reliability with respect to fuel swelling, heat pipe material, and heat-pipe-to-converter-to radiator design constraints will be made. A review of past reactor designs was conducted to establish the dominant factors controlling the size, mass, and lifetime of a nuclear space power system. In order to evaluate the impact of design trade-offs between all of the important design variables, the system was modeled analytically and a computer program written.

The results of the study indicate that fuel temperature and consequent swelling projections dominate the performance projections, particularly at high power levels. Power conversion system characteristics also strongly impact the design.

Two design innovations were developed, one for an in-core reactor design and the second for an out-of-core design, to illustrate approaches for solving the problems associated with both fuel swelling and power conditioning.

TASK #4

TITLE: EVOLUTION OF COUPLED WAVE MODEL FOR ELECTROMAGNETIC TRANSIENTS ON SUPERCONDUCTING BOUNDARIES

PRINCIPAL INVESTIGATOR: DR. GARABET J. GABRIEL (UNIVERSITY OF NOTRE DAME)

The objective of the study was to attempt an understanding of the general behavior of electromagnetic transients on superconductor boundaries such as coils and cavity resonators.

In summary, numerous questions and problems need to be resolved toward the end of achieving a realistic model for coils. A coaxial cavity offers an attractive alternative that might be suitable in some applications. The work at this stage on both fronts is still evolving. Among the many aspects that need attention, the following questions or tasks are recommended.

1. Continue exploration of the electromagnetic field equations in four dimensional tensor formalism appropriate to helical coordinates. This would offer clues for obtaining desired coupled wave equations and for indentificaiton of observable quantities.
2. Attempt to extend the minimum energy principle to helical coordinates to provide a more rigorous foundation for the mode when the dielectric in the coil is inhomogeneous.
3. Attempt an integral formulation using the tensor Green function so as to result in the desired integrals for calculating "inductance" matrices.
4. Attempt a simple experiment on coaxial cavity to test the conjecture presented.

Work on any of the above items is essential to further understanding of transients in unorthodox geometries.

TASK #5

TITLE: SUPERCONDUCTOR EVALUATION FOR SWITCHED INDUCTORS

PRINCIPAL INVESTIGATOR: DR. JAMES C. HO (SCIENTECH, INC.)

The study was undertaken to evaluate various superconductors and insulating coatings for application to high power systems.

In summary, contractor's technical reports to AFAPL on "Enthalpy-Improved Dielectric Insulation for Superconducting Wires" were evaluated. In-house research was made to characterize certain mechanical (microstructure, hardness, adhesion to superconducting wires) and dielectric (breakdown behavior, dielectric constant) properties of the newly developed, thermally conductive ceramic coatings.

Efforts were made towards a feasibility study on the application of certain metallic thin films as both heater and thermometer in transient heat transfer measurements. Such films could have high electrical resistance as required for being heating elements. Preliminary work at other laboratories have shown that their resistance often has a negative temperature coefficient at low temperatures, thus making temperature determinations possible. Their sensitivity and calibration, as well as film preparation, require further studies.

Power supply for the existing Bitter magnet was modified for superconductor testing.

TASK #6

TITLE: INDUCTOR SWITCHING

PRINCIPAL INVESTIGATOR: DR. JOHN P. BARBER (IAP RESEARCH, INC)

PHASE 1

The objective of the program was to conduct research in the areas of inductive energy storage and switching to support AFAPL research and development goals. Three major tasks were conducted during this period; 1) the detailed design of an inductive energy store, 2) assistance to the AFAPL in testing of the high speed circuit breakers/counterpulse system, 3) assessment, design and procurement of instrumentation and data collection for the inductive energy storage/switching test area.

Good progress was made on the inductor design and instrumentation build-up. The inductor should soon be available for connection to the power supply and testing. Instrumentation for current measurement and recording is in hand and will be available for testing. The voltage measure ment approach has not yet been finalized and hardware is not yet available. The high speed circuit breaker/counterpulse system is not completely setup and considerable work remains to complete the interconnection and preliminary testing of this system. Recommendations were made that further effort be expended to

1) complete the setup and testing of the counterpulse system,
2) install and check out the current measuring systems,
3) develop and install isolated voltage and transducer output measuring systems, and
4) integrate the sensors and instrumentation systems with the data recording system.

TASK #6 (Continued)

PHASE 2

The objective of this phase of the program was to implement the recommendations made under the previous phase. The primary emphasis in this phase was to design and implement an integrated instrumentation system in the laboratory at the AFAPL and to insure that the instrumentation system was adequate and available for rotary switch tests. In addition, monitoring of the energy storage and switching literature to maintain an awareness of the most recent developments was continued.

The instrumentation build-up in the laboratory is nearly complete and operation is satisfactory. Recommendations were made that some channels of higher bandwidth recording equipment (such as, oscilliscopes) be integrated into the system to permit observation of higher speed transient events. Also, recommended that continued consideration be given to the acquisition and installation of optical isolators for voltage measurement.

The energy storage coil design appears to be satisfactory. Suggested that consideration be given to operating the coil at liquid nitrogen temperature. This should reduce the resistance of the coil by approximately a factor of 5 and permit a much wider range of operation in terms of current and pulse duration.

Future work might profitably be directed towards counterpulse switching and/or towards more fundamental studies of inductive energy storage, concentrating on the detailed behavior of pulse coils and the transient distribution of current and temperature in normal, cryogenic and superconducting energy stores.

TASK #7

TITLE: SPACE NUCLEAR REACTOR DESIGN ANALYSIS

PRINCIPAL INVESTIGATOR: DR. DEAN L. JACOBSON (ARIZONA STATE UNIVERSITY)

The objective of this task was to perform detailed technology assessment and design studies on spacecraft nuclear reactor power systems for future Air Force missions in the 50-500kw_e, 5-10 year life regime, to identify technology risks, responses and time-oriented development goals, and to project resultant system level performance characteristics.

In summary, US consensus indicates interest in both hundreds of kilowatts and megawatts from SNR's. And anticipated requirements for very-high-power pulse capabilities bring ultraversions such as RBR's and NERVA into the project picture.

For medium and high power levels, the SPAR concept is not directly applicable. But proposals such as the "minipipe" concept emphasize again that the heat-pipe-cooled reactor can fit logically into the SNR evolution at power levels much greater than 100kw_e.

A general approach to SNR development might include the following categories, not necessarily in this order and some in parallel.

Comparison of mission plans with and without SNR

Determination of critical mission requirements

Conceptual designs of nominees

Nominee component, material and safety assessment

Screening analyses of nominees

Candidate selections

Candidate component, material and safety refinement

Detailed parametric-design analyses of candidates

TASK #7 (Continued)

Prototype selection

Plan for development and supporting research

Detailed program definition (resources, schedules...)

Initiation and prosecution of SNR R & D program

Parallel R & D on conversion systems and other components

Such an approach should preclude SNR problems inflicted by presumed pre-eminences of special converters, particular refractory metals or other favored design facets.

Higher power and temperature levels are necessary. An existing technology encourages rather than precludes striving for such attainments. However, the great investment required to provide the US with suitable SNR capabilities demands prudent initial planning.

TASK #8

TITLE: INDUCTIVE ENERGY STORAGE AND SWITCHING FOR SPACE APPLICATIONS

PRINCIPAL INVESTIGATOR: DR. HENRY L. LAQUER (INDEPENDENT CONTRACTOR)

The objective of the study was to determine optimum utilization of inductive energy storage and switching devices for space applications of electrical power systems.

The report contains information which borders on clasified material.

TASK #9

TITLE: A SPECTROSCOPIC STUDY OF THE S_2 MOLECULE FOR COMPARISON WITH LASER INDUCED FLUORESCENCE STUDIES

PRINCIPAL INVESTIGATOR: RALPH E. OBERLY (INDEPENDENT CONTRACTOR)

This study is to provide a literature search for the existing rotational and vibrational constants of S_2 which pertain to the transitions in the 2800-7000A spectral region. The initial steps leading to the production of a theoretical fluorescence spectrum based on selective excitation have been taken. However, significant additional work is needed in order to generate useful constants from the literature data.

It is suggested that the following steps be followed in order to continue this work:

(a) Continue the computations needed for a more complete set of rotational constants.

(b) Incorporate the computed constants from "a" into the HP9845B programs in order to more fully and accurately determine rotational line position programs.

(c) Add rotational line intensity and line width information to the rotational line position programs.

(d) Extend the line position and intensity programs to include a summation routine for adding spectral intensities from all lines at a particular wavelength. This step is somewhat simplified for LIF spectra as only one, or a few, upper vibrational states are occupied at any one time. Consequently, fewer rotational lines enter into the summation than if all upper state levels are considered as being populated.

TASK #9 (Continued)

(e) Possibly extend the existing rotational data in the literature by collecting and studying new experimental absorption and/or emission data for S_2 in the B-X system.

All of these steps are necessary to fully support on-going laboratory work in LIF studies of S_2. A modeled spectrum based on realistic physical constants is necessary in order to predict where LIF line spectra can be most efficiently produced. The literature data that now exists is sufficiently incomplete that no accurate predictions can be made. Obtaining an accurate description of experimental results is at best difficult.

TASK #10

TITLE: MICROWAVE INTERFEROMETER FOR ELECTRON DENSITY MEASUREMENTS

PRINCIPAL INVESTIGATORS: DR. MERRILL L. ANDREWS AND PETER T. LAMM

(WRIGHT STATE UNIVERSITY)

The objective of the study was to measure electron densities in pulsed discharges. The discharges included time durations of 100 nanoseconds or less and decay times typically of several microseconds. A Fabry-Perot microwave interferometer operating at approximately 55 GHz was chosen as the best system for electron density measurement in the plasmas of interest. The microwaves can propagate through quartz tubes containing the plasma and will not perturb the plasma since no added structure is required in the plasma tube and the microwave fields are too small to cause heating or additional ionization. Also, most of the components needed for the interferometer are available in the laboratory. This sytem will measure line densities with a minimum sensitivity of $10^{12}cm^{-2}$ and allow electron densities as high as $10^{13}cm^{-3}$ before non-linear effects near cutoff become significant. The spatial resolution of the Fabry-Perot is well defined by the profile of the Gaussian beam where the diameter of the beam at the center plane of the resonator may be varied from 1.2 - 2.4 cm depending on the spacing chosen between mirrors over the range of 32 - 25 cm. For large diameter plasmas such as the silane reactor plasma with a 10 cm diameter, this spatial resolution will lend itself to reasonable Abel inversions for determining electron density profiles.

TASK #11

TITLE: HIGH ENERGY DENSITY NON-AQUEOUS BATTERIES

PRINCIPAL INVESTIGATOR: DR. VIJAY K. GUPTA (INDEPENDENT CONTRACTOR)

The objective of this task was to optimize the anode composition for the calcium thionyl chloride system in an attempt to reduce anode corrosion.

The purpose of this effort was to fabricate complete cells consisting of calcium and/or calcium-lithium alloy anode, carbon cathode, and thionyl chloride electrolytes. The cells were to be investiaged for open-circuit potentials, stability, passivation characteristics, and limiting discharge rates.

A change in the elctrolyte salt was suggested as the best way to solve the anode corrosion problem, but the calcium-lithium alloy electrodes may still be attractive in providing a higher melting point than lithium and a higher OCV than calcium.

Further effort is needed to search a suitable salt as an additive to the electrolyte.

TASK #12

TITLE: SPACE NUCLEAR REACTOR POWER SYSTEM DESIGN ANALYSIS

PRINCIPAL INVESTIGATOR: DR. JAMES F. MORRIS (ARIZONA STATE UNIVERSITY)

The purpose of this task is to conduct studies of advanced nuclear power systems technology options for future high power military space missions. The scope of the task requires assessment of a variety of reactor heat source candidates, energy conversion techniques, and heat rejection methods applicable to high power base load and pulsed power missions. The objectives of this study are to assess technology feasibility of candidate reactor power system configurations, to identify key technology deficiencies which currently limit feasibility, and to provide recommendations concerning technology development.

The efforts of this task has resulted in the publication of the following technical articles:

- o "Pre-1973 Technology Enables Near-Term US Space Nuclear Power" (IEEE COPS),
- o "Thermionic-Energy-Conversion Implications of Space-Nuclear-Reactor Ultralloys" (IEEE COPS),
- o "Arizona State University Research Related to Thermionic Energy Conversion" (IEEE COPS),
- o "Ultralloys for Nuclear Thermionic Energy Conversion" (IECEC),
- o "Space-Nuclear-Reactor Questions" (IECEC),
- o "Better, Cheaper In-Core Thermionic Energy Conversion (ICTEC) with Pre-1973 Ultralloys" (IECEC), and
- o "Thermionic-Converter Pulsing, Switching, Oscillating and Lasing".

TASK #13

TITLE: EXPERIMENTAL & ANALYTICAL CORRELATION OF INTEGRAL HEAT PIPE/ENERGY STORAGE UNIT

PRINCIPAL INVESTIGATOR: DR. BEDRU YIMER (UNIVERSITY OF KANSAS)

An experimental and analytical work was performed to evaluate and correlate the performance of an integral heat pipe/energy storage unit. The experimental work included the determination of the thermal conductivity of a flouride salt with weight composition of LiF-41.27%, MgF_2-48.76% and KF-8.95%. The thermal conductivities for the solid as well as the liquid phases of the salt were evaluated. The solid phase thermal conductivity was experimentally determined by Dynatech R&D company using the comparative method. Thermal conductivity values were successfully obtained at three data points (4.283 Btu/hr.^{o}F ft at 212^{o}F, 3.22 Btu/hr. ft.^{o}F at 482^{o}F and 1.31 Btu/hr. ft.^{o}F at 1022^{o}F).

The effective thermal conductivity of the integral heat pipe/thermal energy unit both in the solid and molten states of the phase change salt was experimentally determined in the Mechanical Engineering Department Laboratory at the University of Kansas. The steady state and quasi-steady state methods were used for the experimental evaluation.

An existing analytical model was expanded to include variations along the longitudinal axis of the unit. The accuracy of the model was verified using two independent methods. The model was used to obtain analytical results of the performance of the integral heat pipe/thermal energy storage unit. The experimentally evaluated thermal conductivity data for the phase change salt was used in the analysis. Experimental and analytical results were compared and correlated. Agreement was very good.

TASK #13 (Continued)

The following recommendations are made for future investigation:

1. Development of a phase change material which can undergo phase transformation at one eutectic temperature.
2. Experimental investigation to determine fusion temperature, latent heat of fusion, thermal conductivity, and other critical thermophysical properties more accurately.
3. Development of an analytical model that will take change in density and convection effects into consideration.
4. Conduct performance tests using more accurate instrumentation.

TASK #14

TITLE: Mk 10 TURBINE BASED RAPID FIRE RAIL GUN SYSTEM

PRINCIPAL INVESTIGATOR: DR. JOHN P. BARBER (IAP RESEARCH, INC.)

The purpose of the study was to determine the performance potential of a single stage Rapid Fire Electric Rail Gun System powered by an existing rocked turbine, the Mk 10. The projectile mass, launch velocity and acceleration limits were provided by the Air Force. The turbine operating characteristics were provided by Rocketdyne. The system concept and the other component characteristics were generated in the program. The primary objective was to determine the maximum firing frequency which could be expected from the system. An additional concern was the size of the system and the performance requirements for the system components.

In summary, it was found that projectiles in the mass range from 0.5 to 1.0 kg can be launched to velocities of 3.0 to 5.0 km/s at frequencies of up to several Hz, using the existing turbine system. The critical technology questions concern the cooling of the generator and inductor. These problems are directly related to the burst duration requirements, which were not clearly defined for the study.

Further study is required to determine the tradeoffs among component requirements, system performance and component performance. Assessment of component feasibility and development requirements should be carried out. Optimized start-up procedures should be studied to determine the best combinations of turbine power reduction, generator excitation and timing. During shutdown, options with and without rail gun firing should be investigated and methods of controlling the rendered energy developed.

TASK #15

TITLE: COUPLED WAVE MODEL

PRINCIPAL INVESTIGATOR: DR. GARABET J. GABRIEL (UNIVERSITY OF NOTRE DAME)

The purpose of the study was to experimentally verify coupled wave model voltage spikes in large coils. The work undertaken in Task #15 was a continuation of earlier work (Task #4) that inevitably broadened to the general topic of electromagnetic transients on conductors, including also evolution of needed mathematics tools. This stems from the fact that no one aspect of electromagnetic transients could be addressed realistically without due regard to related questions. However, the problems were classified broadly under three categories:

1. Geometric fongiruation of conductor boundaries and coordinate systems;
2. Effects of dielectric and magnetic properties of contiguous media; and
3. Nature of current distributions and transition from static to dynamic behavior.

TASK #16

TITLE: SUPERCONDUCTOR EVALUATION

PRINCIPAL INVESTIGATOR: DR. JAMES C. HO (SCIENTECH, INC.)

The objective of the task was to evaluate superconductors and enthalpy-stabilizing coating materials for application to high power systems.

Major effort during the contract period can be summarized as follows:

(1) Critical current measurements were made on ceramic-coated Airco superconducting wires. The specially synthesized coating materials had their thermal properties designed to suppress the conductor temperature increment as caused by internal energy dissipation. Similar experiments were also made on bare conductors as well as on conductors with GE varnish coatings for comparison. No significant effect is observed, which was attributed to the coating materials, presumably due to the too slow current rise rates being tested. Final evaluations will need to be based on high pulse rate tests.

(2) In connection with a computer model on transient heat transfer for superconductors, experimental apparatus was constructed for evaluating heat transfer characteristics of the enthalpy-stabilizing coating materials. These materials are to be applied over a germanium thin film, which is used as a temperature sensor. The germanium film was first deposited onto a stainless steel foil, which acts as a heat source through Joule heating. This arrangement would simulate the superconductors operation, but with controlled levels of power input. Difficulties had been encountered in making the specimens, particularly the deposition of germanium films with appropriate geometry to ensure sensitivity and reproducibility. A lack of suitable deposition equipment needs to be addressed. In the meantime, replacement of germanium by graphite films is being experimented.

TASK #17

TITLE: ANALYSIS OF IMPURITY BAND BROADENING AND BANDGAP NARROWING IN Si AND GaAs SEMICONDUCTOR MATERIALS

PRINCIPAL INVESTIGATOR: DR. L. CARLTON BROWN (OHIO STATE UNIVERSITY)

The objective of the task was to apply the bandgap narrowing (BGN) model recently developed by the author at The Ohio State University to Si and GaAs P/N junctions in order to develop the effect on current-voltage characteristics.

The investigation considered donor-donor (or acceptor-acceptor) pair interactions and also donor-acceptor pair interactions subject to a screened Coulomb potential and to a statistically varying nearest-neighbor impurity separation within the interacting pair. By means of variation procedures, the groundstate energy levels of these systems were calculated and used, along with statistical probabilities of occurrence, to obtain the density-of-state structure of the resulting impurity band. Input parameters were temperature, majority and minority impurity concentration. Initial values of the Fermi-energy, carrier concentration, and screening parameter were calculated from simple models of the unperturbed donor (acceptor) level.

The screening parameter found was also an input parameter to the energy-level calculation. Since a corrected value of the screening parameter (and Fermi-level) must be obtained from the resulting energy levels, and corrected energy levels must be obtained from the corrected screening parameter, several iterations were used in order to obtain self-consistent values.

TASK #18

TITLE: INVESTIGATION OF AN ADVANCED FUEL PROCESSOR

PRINCIPAL INVESTIGATOR: DR. MOMTAZ MANSOUR

(MANAGEMENT & TECHNICAL CONSULTANTS, INC.)

The objective of the study was to develop a conceptual design for a logistics fuel processor for fuel cell power plants.

The proposed program put forth an innovative design concept (proprietary to MTCI) that is believed to comprehensively address the Air Force in-service requirements. The philosophy adopted in formulating the design goals and design configuration was one of facing up to the application needs rather than adopting an evolutionary improvement of traditional processor configurations.

The study believes that the proposed concept will provide the fuel and operational flexibility required by the Air Force fuel cell applications. This includes ability to use the Air Force logistic fuels for continuous operation as well as substitute fuels under emergency conditions for short periods of time. The degrees of freedom available in controlling the fuel processor operating conditions will allow flexibility in fuel substitutions by modification of process control without the need for major hardware modification.

TASK #19

TITLE: HIGH-REPETITION-RATE TEMPERATURE MEASUREMENT OF LABORATORY COMBUSTION FLAME BEAM DEFLECTION

PRINCIPAL INVESTIGATORS: DENNIS F. GROSJOAN AND LARRY P. GOSS (SYSTEMS RESEARCH LABS, INC.)

The objective of the study was to develop instrumentation and demonstrate feasibility of high repetition rate temperature measurement from 300°K to 2300°K with accuracy comparable to Coherent Ramon Scattering Measurements.

The report described the first high frequency demonstration of a thermometric technique which can be applied to diverse, practical flame environments. The technique, based on that first described by Zapka involves measurement of the propagation velocity of an acoustic impulse between two measurement points defined by monochromatic beams. The method is nonintrusive at the point of measurement, does not require focus coincidence of multiple beams, and can be used with a number of commercially available high-repetition-rate lasers.

The high-rep-rate application of the optoacoustic laser-beam deflection technique described is the first demonstration of noninstrusive time-resolved temperature measurements in a flame. The relative ease of implementation and the ready availability of suitable pump sources results in this method having wide applicability in combustion diagnostics and modeling.

TASK #20

TITLE: HEAT PIPE AND THERMAL ENERGY STORAGE CORROSION STUDIES

PRINCIPAL INVESTIGATOR: DR. DEAN JACOBSON (ARIZONA STATE UNIVERSITY)

The purpose of the study was to investigate liquid metal corrosion phenomena in metallic heat pipes.

A fifteen foot sodium heat pipe was designed for the development of a thermal power system capable of transferring thermal energy from a solar collector to a Vuilleumier cooler on board a surveillance satellite. Sometime after the end of the research effort in June 1974, the pipe was intentionally exposed to the atmosphere in order to remove some expensive valves. Nearly six and half years later, the pipe was reprocessed. Attempts to remove contaminants in the sodium heat pipe were made by heating and evacuation routines by vac-sorb and vac-ion vacuum techniques. The pipe was successfully restarted in December 1981 when the performance began to degrade quickly and sodium began leaking from the evaporator section and a fire resulted.

An analysis of the pipe failure was begun in February 1983. Extensive intergranular corrosion and cracking was found in the evaporator section of the pipe allowing sodium leakage. The primary heat pipe was the subject of this investigation. The pipe was sectioned and the sodium was dissolved in Dowanol EB. Metallographic and microprobe analyses were performed on post-failure test samples. Intergranular corrosion was observed on the inside surface of the evaporator. Precipitation was also found in the heater area. Microprobe analyses revealed that chromium, molybdenum, iron and phosphorous were rich in the corroded intergranular material but no titanium or aluminum were detected.

TASK #20 (Continued)

A thermodynamic viewpoint is presented to explain the behavior of various contaminants in the sodium. Oxygen contaminated sodium was considered to be dominant in the failure of the pipe. However, precipitates, embrittlement and thermal stresses possibly aided the failure.

TASK #21

TITLE: INVESTIGATION OF DISSOCIATIVE ATTACHMENT

PRINCIPAL INVESTIGATOR: DR. J. M. WADEHRA (WAYNE STATE UNIVERSITY)

The purpose of the study was to provide an understanding of attachments phenomena in excited molecules.

Research activities included the development of a comprehensive review of the process of dissociative electron attachment to various molecules like H_2, N_2, CO and HCl. A new project to investigate dissociative attachment to simple alkali dimers like Li_2 was undertaken. The sources of instability in a previously-developed time-dependent Boltzmann code were revealed. Finally, a few seminars were presented at the Air Force Wright Aeronautical Laboratory. The topics of these seminars were of topical interest and mutual benefit:

a. "Dissociative Attachment to Isotopes of Hydrogen."

b. "Interactions of Positions and Electrons with Atoms and Molecules."

TASK #22

TITLE: SUPERCONDUCTING EVALUATION FOR SWITCHED INDUCTORS

PRINCIPAL INVESTIGATOR: DR. JAMES C. HO (SCIENTECH, INC.)

The objective of this task was to evaluate various superconductors and insulation coatings for application to high power systems.

Most of the work was carried out at AFAPL with Dr. C. E. Oberly as the focal point, only brief descriptions of the major effort during this contract period (May 1, 1984 - March 25, 1985) are summarized as follows:

(1) Continual critical-current measurements were made on multi-filament Nb_3Sn superconductors with specially synthesized coatings for enthalpy stabilization. Dr. Ho participated in a workshop on "Dielectric Insulations for Conductors and Superconductors" in October 1984 at the Westinghouse R & D Center, Pittsburgh, PA.

(2) A new system with peripheral equipment for pressure-quenching CdS has been obtained. It has been put into operation by Dr. S. B. Nam, a National Research Council Associate at AFAPL. Specifically, the system can subject Cl-doped CdS specimens (prepared at the National Bureau of Standards) to very high pressures, followed by liquid-nitrogen-temperature quenching in pressure (i.e. relieving pressure very quickly). Magnetic superconductivity in CdS under such pressure-quenched conditions. Effort is being continued by Dr. Nam.

(3) With Professor John Woolham of the University of Nebraska, Lincoln, NB, vapor grown as well as pitch based carbon fibers were intercalated with H_2SO_4, $EuCl_3$, and Br_2. Electrical properties of the resulting materials have been measured, and were reported at the 17th Biennial Conference on Carbon of the American Carbon Society, June 16-21, 1985,

TASK #22 (Continued)

Lexington, Kentucky. Further work towards possible superconductivity in intercalated graphite is recommended.

(4) Dr. Ho has also provided general consultation and performed services to other participants of the same Scholarly Research Program, upon the requests of Dr. C. E. Oberly.

TASK #23

TITLE: TRANSIENT MODELING OF INSULATION ON SUPERCONDUCTING INDUCTORS

PRINCIPAL INVESTIGATOR: DR. ALBERT MENARD (SAGINAW VALLEY COLLEGE)

The goals of the task were to evaluate the thermal response of various superconductors (SC) and coatings using a transient computer model and determine optimal insulation type and thickness for various pulse scenarios.

The newly developed SC materials appear to offer significant advantages over traditional epoxies as potting materials for superconducting coils that have rapidly changing magnetic fields, e.g. pulsed coils. Vigorous research and development of these materials should continue. Magneto-caloric effects are negligible for these materials and can be ignored except for the information that they generate about the source of the unique properties of these materials. The key thermal property for these materials for use in potted coils is the high specific heat in the 7-10^{o}K range. Research should continue to find the otherwise suitable material with the highest possible specific heat in this range.

Parts of this work were presented in a 40 minute invited paper "Thermal Modeling of Superconducting Insulations" given at a symposium "Dielectric Insulations for Conductors and Superconductors under Severe Environments" held in Pittsburgh on October 31, 1984. Additional information on this project is contained in the paper "Computer Simulation of Transient Heat Transfer from Superconductors Coated with a New Class of Dielectric Materials" which was submitted to publication to Cryogenics.

TASK #24

TITLE: COUPLED WAVE MODEL OF RAILGUN COMMUTATION

PRINCIPAL INVESTIGATOR: DR. GARABET J. GABRIEL (UNIVERSITY OF NOTRE DAME)

The goal of the task was to experimentally verify coupled wave model voltage spikes in electromagnetic railguns that require commutation of megamperes from large coils to the railgun.

The travel time of a disturbance around a single turn and the turn-to-turn coupling are the dominant aspects by which the Coupled Wave Model departs from circuit theory in describing transient response of coils over short time scale. The excellent agreement of the model with experimental observations motivates confidence in the basic suppositions underlying its theory. As to the problem of high voltage breakdown, it is most likely to occur on the short time scale comparable to travel time per turn, as indicated by computer calculation on a two-turn coil. Success of the model thus far makes it well worth the effort to tackle the more complicated and difficult configurations with a view toward developing refinements that would permit prediction and simulation.

TASK #25

TITLE: ANALYSIS OF ELECTROMAGNETIC AND MATERIALS PROBLEMS IN FABRICATING SUPER-DIFFUSION RAIL CONCEPT FOR ELECTROMAGNETIC LAUNCHERS

PRINCIPAL INVESTIGATOR: DR. JOHN B. BARBER (IAP RESEARCH, INC.)

The purpose of this task was to analyze and assess the fabrication and materials problems for a fully transposed rail concept.

The first subtask undertook was to analyze the diffusion process in transposed rails. It was concluded that transient phases of transposed rail operation are probably very short and do not represent a serious thermal problem. The transfer of current from the "liner" to the transposed conductor does not involve electrical contact between the conductor and the liner. The performance of these contacts may be critical. If the contact is adequate (electrically), then transfer of current to the conductor will occur and no significant current will flow in the liner.

The transfer of current to the conductor will be either "resistive" or "inductive". In the resistive case, current is shared between the conductor strands and the liner according to the apparent DC resistance of each element. In the inductive case current is induced in each strand/liner loop by the advancing armature. Which transfer mechanism acts is determined by the time constant (L/R) of the strand/liner loops. If the transit time of the armature along a loop is short with respect to the time constant, then inductive transfer will occur. If the transfer time is long, then resistive transfer will occur.

No matter which transfer mechanism is acting, the transfer will occur in a short time with respect to the launch time (or it will not occur at all). The thermal load on the rail is then nearly all in the conductor (as

desired) and the current density is, presumably, constant. The resistive heating load is then easily computed. The cross section of the conductor can be selected to control the thermal load.

Critical aspects of rail performance and the impact they have on fabrication were discussed. Good electrical contact with the liner is essential. Good interfilament insulation is also essential. Finally, high mechanical strength transverse to the rail is required.

TASK #26

TITLE: THIN FILM GERMANIUM THERMOMETER

PRINCIPAL INVESTIGATOR: PHILIP SWINEHART (LAKE SHORE CRYOTRONICS, INC.)

The purpose of the study was to suggest an experimental design for the heat transfer measurements and fabrication of a large area Germanium Thermometer. An experimental attempt to obtain germanium films of the correct resistivity by standard vacuum evaporation was made.

The report discusses a design study for applying thin film germanium resistance thermometers in heat transfer studies at liquid helium temperatures. Specifically, heat transfer measurements must be made on certain ceramic materials proposed for insulating and stabilizing superconducting windings. The thermometers must have adequate speed and sensitivity to detect boiling transients at the ceramic surface. Seki and Sanokawa have demonstrated that thin film germanium sensors can do this on a stainless steel ribbon insulated with silicon monoxide.

The experimental goal of obtaining heat transfer information for ceramic coatings on metal strip heaters appears to be feasible. Enough work has already been done by others to provide guidelines. Several different types of thermometers can be applied to substrates with the desired response times and sensitivities. If the thin film germanium sensors are too difficult to make with low enough resistances, they can probably be doped with impurities in a conventional manner.

TASK #27

TITLE: HIGH VOLTAGE PULSE TESTING SURVEY

PRINCIPAL INVESTIGATOR: WILLIAM G. DUNBAR (BOEING AEROSPACE COMPANY)

HIGH VOLTAGE PULSE TESTING SURVEY

The Pulse Test Survey summarizes government, industry, and technical reports on high voltage pulse testing of commercial and experimental equipment. The survey details peak voltage and test pulse rise time and fall time as they are applied to evaluate electrical insulation between electrical and electronic system components. Survey findings could be used to specify a pulse test set for certain aerospace systems.

The major tasks reported in the high voltage pulse survey are:

- o A survey of technical literature on the impulse testing of electrical insulating materials, components, and systems.
- o Specifications for the development of a high voltage pulse generating test set.
- o A comparison of pulse testing and partial discharge and electrical-withstanding voltage testing.

The survey results and the former pulse test results show several program benefits.

1. Pulse rise and fall time effect the insulation life.
2. Pulse polarity affects the insulation life and the maximum voltage stress characteristics of the insulation.
3. The electric field stress versus insulation life should be evaluated by test for operation at the critical pulse rise time and for shorter and longer pulse rise times.

4. An evaluation of electrical insulation for long life capacitors should include the probability of partial discharge generation between the plate(s) and film.
5. Work should be initiated to evaluate creepage and flashover of structural insulating materials and potting materials when immersed in pressurized air and other insulating gases.

HIGH VOLTAGE PULSE TESTING PLAN

This pulse test plan contains the configuration, operation and maintenance test requirements, equipment requirements, and procedures for high-voltage pulse testing of aerospace parts and equipment. The plan details peak voltage and test pulse rise time and fall time as they are applied to evaluate electrical insulation within electrical and electronic system components.

The major tasks reported in the high voltage pulse test plan are:

- o The selection of test articles based on test data obtained for the components evaluated in Contract F33615-79-C-2067.
- o Test article preparation shall be called out for each specific type test article(s).
- o Test parameters shall be established for each test and test sequence in conjunction with "High-Voltage Testing: Specifications and Test Procedures" (AFWAL-TR-82-2057, Volume II) and the Pulse Test Survey (AFWAL-TR-85-2079).
- o Pulse characteristics shall be determined based on the component design and operating characteristics.
- o Comparative test criteria shall be made for each selected component to evaluate each specific test in the test sequence.
- o Test result evaluation guidelines shall be established.

TASK #27 (Continued)

A modification of the "High Voltage Testing: Specifications and Test Procedures" (AFWAL-TR-82-2057, Volume II) will be determined by various test articles performances to several pulse configurations and magnitudes. The following recommendations to the tests are presented.

- o Test a few specific type test articles.
- o Test each test article with several pulse configurations.
- o Statistical data should be used to analyze the test article characteristics response to the pulse configurations with respect to pulse rise time, pulse width, pulse decay time, pulse magnitude, and number pulses to determine life aspects.

Selected test articles should be tested to failure to establish testing limits. Some test articles should be tested with intermittent visual, partial discharge, and x-ray examinations to establish failure mechanism initiation.

TWTA LIFE TEST PLAN

The Pulse Test Survey summarizes government, industry, and technical reports on high-voltage pulse testing of traveling wave tubes and the required high-voltage power supplies. The survey emphasizes the reliability testing and evaluation required to produce long-life, high-reliability TWTA's. The major objective of this program is to produce a high voltage test plan for the TWT's and the high voltage power supplies for the TWTA's.

The major tasks reported in the TWTA life test plan are:

- o A review of technical literature on the testing of electrical insulating materials, components, and systems for high-voltage power supplies.

TASK #27 (Continued)

- A test plan for long-life reliable high-voltage power supplies.

The airborne high-voltage power supplies and traveling wave tubes for the TWTA's, assess the design techniques and tests required to establish long-life, high-reliability units with significant cost and performance improvements over the present systems. To ascertain the high performance for flight hardware, the testing must be continuous with as least one TWTA drawn from the production lot every nine months for evaluation. Any degradation in performance would be cause to review the manufacturer's quality and production procedures.

TASK #28

TITLE: COMPOSITE ALUMINUM CONDUCTOR

PRINCIPAL INVESTIGATOR: DR. JAMES C. HO (SCIENTECH, INC.)

The objective of this task was to design a composite aluminum conductor for liquid hydrogen service and provide a billet mockup for possible extrusion. The successful feasibility study can be summarized as follows:

(1) A powder-metallurgically synthesized Al-Fe-Ce alloy was first identified as the most suitable matrix material for the composite conductor. Apart from its lightweight, good thermal conductivity, the alloy is compatible in workability with high purity aluminum. Furthermore, its major alloying elements (Fe, Ce) do not diffuse during processing the composite conductor, thus maintaining the purity of the aluminum filaments.

(2) A composite conductor (Al-Fe-Ce/1100 Al) containing 133 filaments was extruded and restacked several times to reach a total area reduction of 100,000. The filaments maintained their geometry.

(3) Another conductor (Al-Fe-Ce/H.P. Al) with 7 filaments showed that the filaments had a residual resistivity ratio of 900, not too much degradation from their original conditions.

(4) Two papers based on these results were presented at the 5th IEEE Pulsed Power Conference and the International Cryogenic Materials Conference.

(5) An invention disclosure entitled "A Composite Aluminum Conductor for Pulsed Power Applications at Liquid Hydrogen Temperatures" has been filed (AF Invention No. 16952). Dr. C.E. Oberly (AFAPL), Dr. H.L. Gegel (AFML) and Dr. James Ho are co-inventors. The invention disclosure identified the U.S. government to receive the entire title to the invention.

TASK #29

TITLE: LONG PULSE HOMOPOLAR GENERATOR LOAD

PRINCIPAL INVESTIGATOR: DAVID P. BAUER (IAP RESEARCH, INC.)

The objective of the task was to design, fabricate and integrate a suitable load into the Long Pulse Homopolar Generator and Pulsed Power "Bread-board" System.

A variable resistance, low inductance, high current resistor has been designed, fabricated, and delivered to Wright-Patterson Aero Propulsion Laboratory. The resistance of this resistor can be varied from 0 to 3 milliohms. The resistor is designed for continuous power dissipation of 300 kW at 10 kA current. All initial verification tests have been performed on the resistor. Final testing of the load was not on this contract.

TASK #30

TITLE: THERMIONIC RESEARCH PLANNING

PRINCIPAL INVESTIGATOR: DR. JAMES F. MORRIS (ARIZONA STATE UNIVERSITY)

The objective of the task was to support mutual AFOSR and AFWAL thermionic research planning.

The following technical papers have been published in support of the task objective:

- "Better, Cheaper In-Core Thermionic Energy Conversion with Pre-1973 Ultralloys," for the Thermionic Power Generator Session of the Nineteenth Intersociety Energy Conversion Engineering Conference, August 1984,
- TEC-planning outlines entitled "Planning Inputs for Long-Range Research on Thermionic Energy Conversion," were sent to members of the technological community interested in TEC programmatics. The feedback was used to help plan the agenda for a January 1985 AFWAL, AFSOR TEC-Research Meeting.
- "Oscillations in Thermionic Energy Conversion," October 1984.
- "Ultralloys for High-Temperature High-Power Applications in Space," for DOE report.
- "Thermionic Energy Conversion for Space-Power and Terrestrial-Topping Applications," for an International Telecommunications Energy Conference.
- "Decrease Creep for Increased Space Power," for an AFOSR study.
- Scheduled March 1985 meeting on "High-Energy Futures Based on Thermionic-Conversion Research", at Arizona State University.

TASK #31

TITLE: SOFTWARE MAINTENANCE AND SUPPORT

PRINCIPAL INVESTIGATOR: DR. JAMES C. BOWERS (INDEPENDENT CONTRACTOR)

The task objectives were the following:

(1) Perform all the necessary changes, corrections and updates to make SUPER*SCEPTRE fully operational on the WPAFB CYBER/NOS system.

(2) Perform all of the conversions and changes necessary to make an interactive graphics version of SPICE fully operational on the CDC/NOS system.

(3) Use existing and new software products to insure both of the above utilize all of the latest features available.

(4) Support other related CAD and modeling efforts as required during the term of this agreement.

Final report consists of a computer program and a user's manual developed to support computer aided design software used by AFWAL. The main software items supported are SUPER*SCEPTRE and SPICE.

TASK #32

TITLE: HIGH TEMPERATURE ADVANCED THERMIONIC CONVERSION

PRINCIPAL INVESTIGATOR: DR. JAMES F. MORRIS (ARIZONA STATE UNIVERSITY)

The goal of the task was to investigate ultra-high thermionic electrode current density theoretically and experimentally, and verify experimental data achieved by Krachino and Matskeevich of the USSR using unignited mode thermionic converters.

The following technical articles have been published in support of the task objectives:

- "TEC and Ultralloys for High-Power Space Systems," for presentation at the Twentieth IECEC, August 1985.
- "Some Ultralloy Implications of a Revised Expression for Miedema's Alloy-Cohesion Relationships," September 1985.
- "Aspects of Cs, Ba Knudsen Ultrahigh-Temperature TEC" and "Material Considerations for Ultrahigh-Temperature Thermionic Conversion in Space Nuclear Power," for the Twenty-first IECEC, August 1986.
- "Tungsten Sintering Activated by Eutectics Comprising Additives to Improve Ultralloy Performance and Processing for High-Temperature Nuclear Space Power," May 1986.
- "Ultrahigh-Temperature Thermionic Energy Conversion and Ultralloys for Multimegawatt Space Nuclear Reactors," July 1986.

TASK #33

TITLE: CRYOGENIC FLUID STORAGE AND EXPULSION TECHNOLOGY

PRINCIPAL INVESTIGATORS: DR. K. SREE HARSHA AND JAY D. PINSON II

(SAN JOSE STATE UNIVERSITY)

The objective of the task was to conduct a study and analysis of the technologies required for the long term (5 - 7 years) space storage of cryogenic fluids and their subsequent explusion at high rates for use in large prime power systems.

The following is a summarization of the findings and analysis:

* Improvement in long term storage technology is required if a large LOX/LH_2 prime power system is to become economically viable.
* Limited available technologies restrict the configuration options for design.
* The lack of system trade-offs and analysis for various configurations based on selected performance parameters restrict the detail analyses for specific technology improvement payoffs.
* Validation is needed in the area of multilayer insulation technology. It is recommended that an investigation, including testing to validate expected performance as related to thickness of layers, tank size/area, shields, joints, degradation with time and material selection, be conducted. Results would be a design handbook for use of multilayer insulation.
* Materials analysis study that would examine the use of various materials, including advanced materials, for tanks, supports, pipes and struts. This is a major payoff area where the

TASK #33 (Continued)

materials selection and design techniques would have a major impact on overall performance.

* Configuration and performance analysis for a total system need to be developed to realistically identify technology needs. This type of computer simulation and analysis is necessary to assist in the development of technology programs for achievement of an operational system.

* Thermal management of such a complex system will be most difficult. The development of thermal modelling and simulation techniques for controlling of total integrated systems is of major importance.

TASK #34

TITLE: MEGAWATT SPACE POWER SYSTEMS EFFLUENT MANAGEMENT STUDY AND ANALYSIS

PRINCIPAL INVESTIGATORS: DR. DONALD J. MYRONUK AND CHARLES A. POST

(SAN JOSE STATE UNIVERSITY)

The purpose of the report was to identify the types, quantities, sources and effects of effluent contamination produced by an open cycle, space based turoalternator operating on liquid hydrogen and liquid oxygen.

Contaminant materials can come from several sources, including spacecraft power systems, cooling systems, reaction control thrusters, material outgasing, and launching of experimental packages.

Surface contamination can cause changes in characteristics and degradation of performance in thermal control surfaces and sensitive optical surfaces. Spacecraft designs generally have sensitive surfaces well removed from propulsion systems with no-line-of sight between the surface and effluent plume. Contamination can still occur due to collisional scattering of molecules in the plume.

The quantities of effluent can be reduced by adjusting the operating conditions of the turbine. The quantities of contamination actually reaching sensitive surfaces can be reduced by several methods including shielding of sensitive surfaces, the use of purge gases, and careful placement of nozzles and orifices.

TASK #35

TITLE: PRELIMINARY INVESTIGATIONS OF ADVANCED AIRCRAFT POWER SYSTEM TOPOLOGIES

PRINCIPAL INVESTIGATOR: JAMES L. MITCHELL (INDEPENDENT CONTRACTOR)

The objective of this investigation was to identify the electrical power system topologies for Air Force fighter type aircraft projected for the 1990's. To accomplish this investigation, CSD and VSCF generating systems, high voltage direct current, high frequency, variable voltage/frequency generation and distribution, solid state power control devices, and motors were assessed.

The recommendations for technology developments to meet the 1990's objectives are:

1. Develop two configurations of a 300KW, 115/203 volt, 400HZ generator with emphasis on minimum weight and volume. The two configurations are to be:
    - o A generator for mounting on an engine or airframe type gear box.
    - o A generator mounted on the engine shaft and as an integral part of the engine.
2. Develop an ELMS with an integrated fault projection and built-in test capability.
3. Investigate a light weight 270 volt DC transmission and control system.
4. Develop miniature, light weight, high speed, solid state, remote resettable power system control devices such as circuit breakers (10 to 150 ampere rating), switches and relays. As an objective,

TASK #35 (Continued)

these devices should have less volume and weight than the comparable electromechanical units, and also develop ribbon type cable with miniaturized rack and panel connectors with emphasis on shielded conductors, co-ax configurations and terminations.

5. Conduct a trade study to determine the advantage and feasibility of using a 50 to 110 volt DC electrical power system.
6. Develop an APU having an electrical output capacity of 300KW and having an all environment (fighter type aircraft environment) operational capability.
7. Investigate a stored energy power supply (battery with charger) having an output capacity of 1000 ampere at 270 volts.
8. Develop a series of motors having output ratings up to 150 horsepower. These motors should be designed to operate on 270 volts DC, variable voltage and frequency, and high frequency (motor speeds from 25K to 50K RPM).
9. Develop wire, insulation, circuit control devices (relays, circuit breakers, and switches), and a magnetic material capable of operation above 500^{o}F ambient temperatures. As an objective, the magnetic material characteristics should have a significant improvement over such materials as samarium cobalt.

TASK #36

TITLE: NEUTRON ACTIVATION ANALYSIS OF SOLAR CELLS

PRINCIPAL INVESTIGATOR: ARIZONA STATE UNIVERSITY

The goals of the task are to determine the effects of high energy (14 Mev) neutrons on solar cell performance and to determine to what degree the permanently induced neutron damage is due to activation and subsequent transmutation of the semi-conductor material.

Lt. Robert Morris visited the Arizona State University's Radiation Measurements Facility on April 22 and 23 for the purpose of using their Neutron Generator. He completed his task of assessing trace elements in silicon wafers on April 23, 1985.

TASK #37

TITLE: THIN FILM COMPOSITE MATERIALS

PRINCIPAL INVESTIGATORS: DR. MITCHELL THOMAS AND DAVID H. CHITTENDEN

(L'GARDE, INC.)

The objective of the task was to determine thin film composite materials thermophysical and thermochemical properties and compatibility with expandable spacecraft radiator concepts.

The work shows the effect of operating variables and materials of construction on the size and shape of an inflatable radiator. For these comparisons the basis was the vapor volume that would be generated by a waste heat rate of 50 MW for 200 seconds. The basic problem encountered was that the strength of most available films is not great enough to sustain the working pressures in reasonably sized spheres or cylinders.

A range of water saturation temperatures was used from 283^{o}K to 394^{o}K. It was possible to contain the vapor in 10 cylinders of 200 meters length, but only at the lowest temperature and pressure for Kapton H film.

Six working fluids, ammonia, trichlorofluoromethane, methyl alcohol, carbon tetrachloride, water and ethylene glycol were compared with all vapors at 75^{o}C. Since the high boiling fluids generate less pressure at the working temperature, they are much easier to contain in an inflatable structure.

When calculations were made for both spheres and cylinders, the system weight was higher for cylinders because of the higher surface to volume ratio. At low pressures where cylinders were short, they would hold about the same volume as spheres; at higher pressures, long cylinders were more

practical than spheres for a given vapor volume and available film thickness.

To contain a given vapor volume multiple cylinders or spheres can be used. However, the film thickness of the container decreases in proportion to the cube root of the number of spheres, and to the square root of the number of cylinders, so the advantage of multiple units is diminished.

Kevlar fiber reinforced film has enough strength and thickness to hold water vapor more easily than any unreinforced film. For example, 7 Kevlar spheres of radius 8.65m could be used with a water saturation temperature of $348^{o}K$.

General conclusions were:

1. The number of spheres or cylinders needed is:
    a. Directly proportional to the heat load.
    b. Inversely proportional to (film tensile strength x film thickness). Therefore a slightly stronger film is a big improvement.
    c. Greatly increased by higher fluid volatility.
2. The weight of film in the system is:
    a. Directly proportional to the heat load and to the temperature.
    b. Inversely proportional to the tensile strength of the film.
    c. Higher for fluids of low molecular weight and low latent heat.

TASK #38

TITLE: EXPERIMENTS TO SUPPORT DEVELOPMENT OF THE DOUBLE WALL ARTERY HEAT PIPE (DWAHP)

PRINCIPAL INVESTIGATORS: DR. LOUIS C. CHOW AND DR. WILLIAM L. GROSSHANDLER

(WASHINGTON STATE UNIVERSITY)

The objective of the task was to obtain a correlation for maximum heat flux of the evaporator sections of the DWAHP and to measure the thermal conductivity of screen wicks saturated with a heat pipe fluid.

The following conclusions were drawn from the theoretical and experimental analyses performed on layered cloth heat pipe wicks:

1. The mean gap conductance model satisfactorily predicts the trends of layered cloth wick effective conductivity in the region $\omega > 1$.
2. The mean gap conductance model predicts a maximum and minimum possible effective conductivity enhancement. The maximum value is approached as the ratio β/α approaches 1/2 and $k^* > 100$. This shows that the effective conductivity is limited primarily by the fluid conductivity.
3. An accurate correlation for the data can be determined given sufficient repetition of the experiments.
4. In the region $\omega < 1$, contact conductances and correlations for multiple layers of cloth become dominant factors in predicting effective conductivity.

Further work is justified to improve the understanding of heat pipe wicks. The following recommendations were made:

1. Repetition of the experiments would better establish the validity

TASK #38 (Continued)

of the data and provide a sound basis for correlations.

2. The cause of the scaling discrepancy between the 150 mesh copper and the other experiments should be determined.

3. Measurements of the effective conductivity for materials in the range $0 < k^* < 20$ should be made to compare with theory.

TASK #39

TITLE: TEST PLAN FOR HIGH CURRENT CONDUCTORS

PRINCIPAL INVESTIGATOR: MITCHELL D. HOENIG (MIT)

The task objective was to provide conceptual designs for high current conductor tests, conceptual designs for cooling the conductor to 21K with cryogenic helium or hydrogen for 10's of seconds and conceptual designs for energy storing power facilities that can currently or eventually deliver 100's of megajoules of electrical energy to the conductor for 10's of seconds.

The task was divided into four sub-tasks:

Sub-Task I: Internally Cooled Cable Conductor (ICCC) Geometry

The concept of using ICCC for busbars carrying high current is basic to the MIT approach. Originating with Internally Cooled Cabled Superconductors (ICCS), this concept envisions a commercially readily fabricable multistranded cable, compacted and contained in an aluminum jacket or sheath. Degree of compaction would be defined by coolant needs as would wire diameter and hence the cable heat transfer area. Unlike the ICCS, the ICCC must have relatively good lateral porosity to permit coolant flow normal to the flow of current.

Sub-Task II: Selection of Coolant for Test Simulation

Liquid hydrogen is readily available in any foreseen Megaamp Conductor application. It is here the ultimate, practical coolant. The question however remains as to what coolant should be used for testing.

Ultimately liquid hydrogen will have to be used to confirm any prior test results, because its properties are unique. Initial testing can however be carried out using other coolants because of the hazardous and hence expensive nature of hydrogen operations.

Sub-Task III: Choice of Conductor for ICCC

As was pointed out, the use of simple, transposed cable geometries is not fully satisfactory. Although a typical ICCS conductor, useful to superconducting magnet technology projects has the appropriate compaction characteristics of a candidate ICCC, it lacks transverse flow characteristics. These characteristics are needed in order to guarantee adequate flow to, through and from a Liquid Hydrogen cooled (nonsuperconducting) busbar or conductor (ICCC).

Sub-Task IV: Availability of Megampere Power

There appears to be no problem in the availability of power supplies for initial testing in the evaluation of heat transfer and fluid flow characteristics of subsize conductors using high current density Internally Cooled Cabled Conductors (ICCC). On the other hand, a major effort will have to be made in order to acquire power supplies adequate to the demands of high (mega-amp level) current full-scale conductors.

TASK #40

TITLE: CRYOGENIC TEST DEWAR FOR HIGH CURRENT CONDUCTOR

PRINCIPAL INVESTIGATOR: J. BRIAN FEATHERSTONHAUGH (INDEPENDENT CONTRACTOR)

The objective of the task was to explore designs for testing high current conductors in transformer configurations in large, non-magnetic, cryogenic dewars that contain liquid hydrogen.

- The reference section for Advances in Cryogenic Engineering was perused from Volume 15 (1968) through Volume 31 (1984) for relevant material pertaining to applications of cryogenic fiberglass dewars as could be used with liquid hydrogen. The reference section for The Proceedings of the International Cryogenic Engineering Conference (ICEC I through X) were checked for papers pertaining to this investigation.
- Review of the design parameters of nine fiberglass dewars was undertaken.
- The effect of the temperature difference between liquid hydrogen and liquid helium on non-metallic cryogenic materials was researched. The impact of the variance in permeability as results in using liquid hydrogen as compared to using liquid helium was investigated. The consequences of the increased flammability between hydrogen gas and helium gas was ascertained with specific consideration given to the storage vessel being flammable. The relative breakdown voltage between gaseous hydrogen and helium was investigated.

TASK #41

TITLE: EVALUATION OF HIGH TEMPERATURE CONDUCTOR OF MATERIALS

PRINCIPAL INVESTIGATOR: DR. JAMES C. HO (SCIENTECH, INC.)

This task was part of an overall program aimed at identifying and improving various materials for their potential applications as high temperature conductors. Such applications are critical to the development of advanced space power systems. Basically, one needs to incorporate high-temperature strength to high conductivity materials. Several newly developed alloys and composites were considered.

Efforts of this task can be summarized as follows:

1. Electrical conductivity measurements were made on Al-Fe-CE and Cu-Nb samples from room temperature to near melting point.
2. Scanning electron microscopic examinations of a Cu-Nb high current arc electrode tip were made. The results were analyzed in terms of electrode surface damage and its correlation with Nb filament distribution.
3. Magnetic studies on Al-Fe-Ce alloys were made at low temperatures. No long range ordering was observed in either vacuum hot pressed (VHP) or dynamically recrystallized condition.
4. Effort has been initiated on developing advanced switch contact concepts based on high strength materials with enthalpy stabilization. Further research is needed to work out details concerning materials selection and fabrication.

TASK #42

TITLE: HEAT PIPE AND THERMAL ENERGY STORAGE CORROSION STUDIES

PRINCIPAL INVESTIGATOR: DR. DEAN JACOBSON (ARIZONA STATE UNIVERSITY)

The objective of the task was to provide analysis and data to advance the understanding of corrosion mechanisms in high temperature liquid metal heat pipes and thermal storage materials so that reliable, high performance, long-life systems can be designed and built for space applications.

During FY 1986, the following major tasks were performed:

1. Sodium, Inconel 600 Heat Pipe Failure Analysis
2. Work Function Study of Tungsten, Rhenium Alloys for Space Nuclear Thermionics energy Conversion
3. Heat Pipe Test Stand Design and Fabrication
4. Natural Convection in Vertical Partitioned Air-Filled Cavities

The first two tasks resulted in Masters theses. The first was presented at the AIAA conference in Boston in 1986 and the second thesis is being sumbitted for publication. The third task was a senior project which is ongoing. The fourth task was also the result of thesis work on thermal energy storage and has been presented and published during the contract period. Results of the above effort are documented in a final report.

TASK #43

TITLE: FORCE COMMUTATED CYCLOCONVERTERS FOR 400 HZ

PRINCIPAL INVESTIGATOR: DR. MEHRDAD EHSANI (TEXAS A & M UNIVERSITY)

The broad objective of the project was to develop a new family of force commutated direct frequency chargers applicable to aircraft power systems. This objective was divided into two parallel activities: (1) development of the new power electronic circuit topologies of force commutated cycloconverter (FCC); (2) development of the microcomputer based switching control algorithms and programs for the FCC.

Theoretical work on the FCC has produced mathematical expressions for the converter switching functions. These functions were evaluated in a simulation model of the FCC, connected to typical sources and loads.

Fundamental considerations for the design of the control software for the FCC have been established. The trade-offs between real-time vs. look-up table approaches to the control algorithm have been identified.

Present work on the project is continuing on three fronts.

1. Optimal software compromises for a high speed permanent magnet motor drive with FCC is under study.
2. A laboratory experimental model of FCC is under construction.
3. The development of a prototype microcomputer system and the development of FCC control software is underway.

TASK #44

TITLE: PHYSICS OF ZINC OXIDE CRYOVARISTOR IN HIGH POWER SWITCHING APPLICATIONS

PRINCIPAL INVESTIGATOR: DR. WILLIAM LAWLESS (CERAM PHYSICS)

The previous discovery of a ZnO-based ceramic that retains its varistor characteristics down to helium temperatures has the potentially significant application of energy absorption at cryogenic temperatures. This report documents initial studies aimed at exploiting this application and understanding this "cryovaristor" effect. Three initiatives have been undertaken: (1) Measurement of thermal properties; (2) Computer modelling of energy absorption; and (3) Theoretical physics of the cryovaristor effect.

The specific heat and thermal conductivity of the cryovaristor ceramic material are reported from 1.5 to 320^{o}K. Significantly, the thermal conductivity has a large maximum (0.6 W cm^{-1} ^{o}K^{-1}) at 80^{o}K which augurs favorably for energy absorption at liquid nitrogen temperatures.

The method for solving the general heat equation with temperature-dependent parameters is formulated with specific energy-absorption boundary conditions. The method of finite-element analysis is used, and a computer code has been written for numerical analyses.

The theoretical approach to the ZnO cryovaristor has been defined by formulating a model of the material as a three-component composite. The weak temperature dependence of the low voltage resistivity has been explained in terms of variable range hopping; the results are in good agreement with the experiments. As a first approach to solving the cryovaristor composite model, the appropriate effective medium theory approximation was derived.

TASK #44 (Continued)

Finally, an original discrete model of the cryovaristor in terms of a network of resistors and non-linear barriers which is suitable for numerical simulations was formulated, and appropriate algorithms for efficient computer solutions were surveyed.