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HEAT PIPE TECHNOLOGY

ANNUAL SUPPLEMENT 1971

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TECHNOLOGY APPLICATION CENTER
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ANNUAL SUPPLEMENT

1971

ASSEMBLED BY

THE HEAT PIPE INFORMATION OFFICE

of

THE TECHNOLOGY APPLICATION CENTER
INSTITUTE FOR SOCIAL RESEARCH & DEVELOPMENT
THE UNIVERSITY OF NEW MEXICO
ALBUQUERQUE, NEW MEXICO

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PREFACE

This annual supplement to Heat Pipe Technology continues the work begun with the publication of the "Cumulative Volume" in March of 1971. Contained in this supplement are abstracts of documents and patents identified and added to the Heat Pipe Information Office collection during 1971. Also included is a review of the year's highlights in heat pipe development prepared by the technical editor, Dr. K. T. Feldman, Jr.

It is intended that a supplement such as this will be published at the end of each calendar year. In addition, a quarterly update service is available to those who need to keep current on new applications and developments between supplements.

This volume is in large part based on the efforts of Eugene Burch, Director of the Heat Pipe Information Office and Frank A. Baczek II, Staff Engineer, who devoted a vast amount of time and energy in its preparation. Our gratitude also goes to Dr. Feldman of the College of Mechanical Engineering for his assistance, encouragement and guidance. A number of individuals contributed foreign material to this collection, and in particular, the continued cooperation of Dr. C. A. Busse of EURATOM is gratefully accepted and appreciated.

This publication was further made possible by the Technology Utilization Program of NASA, from which the Technology Application Center derives the major portion of its support and by the close cooperation of the College of Engineering of the University of New Mexico.

William A. Shinnick
Director
Technology Application Center
University of New Mexico

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DEPARTMENT OF MECHANICAL ENGINEERING

INTRODUCTION

Dear Reader:

This annual supplement of Heat Pipe Technology for 1971 includes 101 references with abstracts, and 47 patents. When combined with the cumulative volume released in March 1971, the two volumes of Heat Pipe Technology represent a valuable reference source for anyone interested in heat pipes. In addition to compiling and publishing this current bibliography, the Heat Pipe Information Office maintains an extensive library containing nearly all of these articles.

During 1971 the research and development work on heat pipes has shown steady growth, as evidenced by the publications and patents described in this volume. Significant contributions were made during the year on the following fundamental topics: variable conductance heat pipes, the transient analysis of heat pipe operation, the performance limits of steady heat pipe operation, and the dynamics of vapor flow in heat pipes. Experimental papers on artery and groove wicks and on rotating heat pipes were also notable. Heat pipe applications described in articles published during the year include cooling of gas turbines, temperature control of space craft, cooling of electric motors and electronic systems, heat transfer in thermionic and thermoelectric power generators, and heat transfer in cryogenic systems. From the number and diversity of these applications it is apparent that the heat pipe is gradually emerging from the laboratory into the industrial applications area.

Although a considerable effort has been made to insure that the bibliography is complete, readers are encouraged to report omissions to the Heat Pipe Information Office.

Sincerely,

Tom Feldman

K. T. Feldman, Jr.
Technical Editor

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A. GENERAL INFORMATION, REVIEWS, SURVEYS

71047 THE HEAT PIPE - AN INTERESTING HEAT TRANSFER DEVICE
K. T. Feldman, Jr. Mech. Eng. News, vol. 4, no. 2, 1968, p. 24-27 Avail:TAC

A description of the heat pipe, its design and operating characteristics is presented. Organizations actively engaged in heat pipe research are listed and a construction procedure for a simple heat pipe is given. A demonstration of the effectiveness of the heat pipe as compared to other heat transfer devices is outlined.

71048 COOLING WITH HEAT PIPES
F. J. Lavoie, Machine Design, vol. 42, 86 - 91, August 6, 1970, Avail:TAC

The heat pipe principle is briefly discussed emphasizing low weight, high heat transport capability and wide range of operating temperature. A number of examples of the flexibility in heat pipe design and of its use as a part of a structure are given. The range of its application goes from heat transfer problems in the aerospace industry and cooling of electronic equipment to the Thermal Magic Cooking Pin.

71049 ADVANCES IN HEAT TRANSFER - THE HEAT PIPE
E. R. F. Winter, W. O. Barsch, vol. 6, Academic Press, New York, Feb. 1971, 406 p.

One of the five chapters of the book is devoted to the heat pipe. A brief survey of the historic development is followed by a description of the different types of heat pipes and the operating characteristics. An extensive literature survey covers the areas of general literature, material tests, operating characteristics, application, control and theory. A total of 170 references to heat pipe publication from both the United States and Europe is presented.

71050 LIQUID FIN - A NEW DEVICE FOR HEAT TRANSFER EQUIPMENT
J. Madejski, J. Mikielewicz, Int. J. of Heat and Mass Transfer, vol. 14, p. 357 - 363, Avail:TAC

The liquid fin, a system of pipes or loops filled with a liquid, is proposed for implementation in heat exchange systems. It transfers heat from a heat source to a heat sink that is located above the source through conduction and convection of the internal liquid. The operation depends on the gravitational field and the internal heat transport medium has to remain in liquid state over the entire range of operation. A theoretical analysis and experimental results are presented, and a number of applications are given such as high temperature recuperators. A comparison with the heat pipe emphasizes the simplicity of the device and the fact that its operating pressure is independent of the operating temperature, while the effective thermal conductivity of the liquid fin was found to be substantially lower than that of the heat pipe.

71069 HEAT PIPES AND THEIR APPLICATIONS
Jean Geue (Australian Atomic Energy Commission Research Establishment, Lucas Heights). A bibliography, Jan. 1971, 17 p. Australian. Avail: TAC

Ninety-seven references are listed. They are arranged chronologically by year, covering the period 1964 to 1970, and alphabetically by author within each year. Most references are to general engineering and heat transfer studies, but a percentage involves heat pipes in nuclear systems. Reference is made to an abstract from each article.

71070 HEAT PIPES-DESIGN AND APPLICATIONS
R. Semeria. Institute of Fuel, Heat Exchangers Conference, Paris, France. June 15-18, 1971, Paper 23. 16 p. 52 refs. In French. Avail: TAC

The basic concept, design principles, and some practical aspects of heat pipes are reviewed. The underlying hydrodynamic theory is discussed. Special attention is devoted to pressure losses in the stream and liquid phases and to capillarity and gravity effects. Comparisons of theoretical predictions with experimental data are shown to be rather satisfactory in the case category of liquid metals. Thermal considerations, functional limits, and operating fluid selection criteria are examined. Technological problems posed by the choice of materials, capillary structure, and overall geometry are outlined, and the merits of heat pipes in some space and ground applications are briefly reviewed.

71071 NIMROD OPERATION AND DEVELOPMENT QUARTERLY REPORT, 1 APR-30 JUN, 1970
Gt. Brit. National Inst. for Research in Nuclear Science, Chilton, Rutherford High Lab. (RHEL/R-206) 14p. Avail: TAC

The Nimrod beam was on for high energy physics research for 89% of HEP scheduled operating time. Four experiments were completed and seven continued through this quarter. A heat pipe transport system which increases the operation effectiveness of liquid hydrogen targets is described. The development of wire grid electrodes in electrostatic separators, resulting in very large reductions in conditioning times coupled with lack of sensitivity to contamination, is reviewed. Some preliminary notes are given on resonant extraction system tests on X3, Nimrod's third extracted proton beam.

71101 NEW DIRECTIONS IN HEAT TRANSFER
Howard W. Markstein, Associate Editor, Electronic Packaging and Production, August 1971, Avail: TAC

The report covers methods of cooling electronic equipment when high heat transfer rates are called for, or when temperature stabilization is required. Cooling techniques reviewed are liquid heat exchangers, heat pipes, thermoelectric coolers, and forced air systems.

B. HEAT PIPE APPLICATIONS

B. 1 General Applications

71051 "HOT ROD" FOR THE KITCHEN IS HOT NEW INVENTION
N. Carlisle, Science and Mechanics, Nov. 1970, 3 p., Avail:TAC

A practical application of the heat pipe, a device originally developed for space applications, is presented. The Thermal Magic Cooking Pin to be inserted for example into a roast, accelerates the cooking process by transporting heat from the hot oven atmosphere to the center of the meat. The cooking time can be decreased by more than 50 percent.

71052 LIQUID AND VAPOUR COOLING SYSTEMS FOR GAS TURBINES
J. P. Edwards, London Aeron. Res. Council, 1970, 18 p. refs., National Gas Turbine Establishment, Pyestock (England) Supersedes ARC-30986, (ARC-CP-1127; ARC-30986)
Avail:TAC

The application of several types of liquid and vapor cooling systems to gas turbine blades is discussed. Emphasis is placed on systems suitable for continuous operation. The application of the heat pipe concept to stator blade cooling is discussed in some detail and a tentative design study presented.

71072 HEAT PIPE APPLICATIONS
G.W. Knowles. In: Education in Creative Engineering; MIT, Symposium, MIT, Cambridge, Mass., April 16-19, 1969, Proceedings, p. 43-71, 5 refs. Avail: TAC

The objective of heat pipe applications is to move heat without application of additional energy and with an uncommonly small temperature difference between source and sink. An application of heat pipes to the OAO as a structural isothermalizer is discussed. The fine-pointing accuracy required of OAO demands a passive thermal control, yet structural gradients have to be minimized. The heat pipe fulfills this need. Ring-shaped heat pipes were designed for removable installation within the experiment tube structure. Load analysis was derived from overall spacecraft thermal network analysis. Fitting of circular grooved pipes to the spacecraft was accomplished by shape facsimile transfer to preassembly fixtures. Experimental and acceptance testing confirmed design selections and performance predictions. Future applications of heat pipes for structural isothermalization call for integration of pipes into load-bearing structure. New design and fabrication technique will be required to accomplish this.

71073 CONSIDERATIONS ON PRECISION TEMPERATURE CONTROL OF A LARGE ORBITING TELESCOPE
S. Katzoff, NASA Spec. Publ. 233, (Optical Telescope Technol.) Apr. 29-May 1, 1969, Huntsville, Ala., p. 417-24. Avail: TAC.

Calculations relative to the problem of quantitative specification of temperature uniformity and constancy of a large orbiting telescope is discussed with considerations for being able also to specify telescope operating temperature, materials, environment and types of construction and operation. An idealized configuration of a large telescope tube has been studied in a radiation environment corresponding to synchronous and to near-earth orbits.

71074 TEMPERATURE STABILIZATION WITH HEAT PIPES
K.R. Schlitt (Commission of European Communities, Joint Nuclear Research Centre - Ispra Est. (Italy), Materials Dept. - Direct Energy Conversion, Luxembourg, March 1971), 78 p. In German. Avail: TAC

Heat pipes for changing heat fluxes can be used for controlling their temperatures if they are partly filled with rare gas. The experimental results of the change of temperature between heat fluxes of 0.5 and 1.0 KW are 0.5% for a self-controlled water-cooled heat pipe and 2.2% for a corresponding radiation-cooled heat pipe. The results also show that the temperature stabilization is strongly influenced by the change of the rare gas temperature during operation, especially when the partial vapor-pressure of the working fluid in this zone takes on a non negligible value.

71075 LARGE TELESCOPE EXPERIMENT PROGRAM VOLUME 1, PART 1
Perkin-Elmer Corp., Norwalk, Conn. Optical Group. Contract NAS8-21497. (NASA-CR-102768; Rept - 9800-Vol 1- Pt.-1) 27A pr 1970, 370p. ref. Avail: TAC

The design requirements for the telescope system are summarized and the various components of the system are described and illustrated. The primary objective of the program is to develop a three-meter monolithic diffraction-limited system from a precursor two meter system. The technological gaps to be overcome and the precursor mission profile are discussed.

71076 CHARACTERISTICS OF SIX NOVEL HEAT PIPES FOR THERMAL CONTROL APPLICATIONS
A Basiulis and M. Filler (Hughes Aircraft Co., Torrance, Calif.). American Society of Mechanical Engineers, Society of Automotive Engineers, and American Institute of Aeronautics and Astronautics, Life Support and Environmental Control Conference, San Francisco, California, July 12-14, 1971, ASME

paper 71-Av-29. 9 p. 9 ref. Avail: TAC

Description of the test results and design rationale for choosing the specific configuration of heat pipes developed for certain thermal control applications. The liquid-nitrogen working fluid heat pipe operated at 7.9 W/sq cm with its evaporator end elevated and could be stored safely at room temperature. A circuit-board heat pipe operated from -50 to +80C with a maximum evaporator to condenser differential temperature of less than 10 C. The heat switching device could transfer a preset finite amount of heat at a predetermined temperature, and the flexible heat pipe could be operated in a infinite variety of shapes, including being tied into a knot. The transformer heat pipe, used to control the temperature of the windings of a high power density pulse transformer, had an electrical insulating center section. The controlled temperature heat pipe, which used multievaporator segments, was developed for dissipation of 25 to 175 W at a temperature of -6 to +3C.

71100 RADIAL HEAT FLUX TRANSFORMER
A. Basiulis, R.J. Buzzard (Radio Corporation of America), NASA Pasadena Office Contract NPO-10828, August 1971
Avail: TAC

A radial heat flux transformer employs heat pipe principles to move heat radially from a small diameter shell to a larger diameter shell, or vice versa, with negligible temperature drop, making the device useful wherever heating or cooling of concentrically arranged materials, substances, and structures are desired.

71102 VARIABLE CONDUCTANCE WALL
Neal P. Jeffries, Ronald D. Zerkle, Roger H. Schmidt, ASME-AICLE Heat Transfer Conference, Tulsa, Oklahoma, August 15-18, 1971, 5 p., Avail: TAC

A Variable Conductance Wall (VCW) is a device which can vary the thermal conductance of a wall or plate over a wide range. This device uses internal evaporation and condensation of a working fluid contained within the wall. The variation in heat transfer through the wall is obtained by mechanically disconnecting capillary wicks which are used to pump the working fluid from the condenser to the evaporator. In this way the heat flow can be turned "off" or "on" (i.e. the heat flow may be made relatively small or large), or the conductivity can be varied continuously.

A simplified analysis of the operation of the VCW was found to give agreement with experimental data. The experimental model was operated horizontally with heating at the upper surface, and it gave a range of thermal conductivities which vary by a factor of over 100. The analysis also shows how this range may be extended futher.

71103 INTERCELL PLANAR HEAT PIPE FOR THE REMOVAL OF HEAT DURING THE CYCLING OF A HIGH RATE NICKEL CADMIUM BATTERY

Mahefkey, E.T.; Kreitman, M.M. (Air Force Aero Propul. Lab., Wright-Patterson Air Force Base, Dayton, Ohio), J. Electrochem Soc., 1971, p. 1382-1386, Avail: TAC

Two 22-A-hr Ni-Cd cells were continuously cycled at a 1 C charge rate and a 2 C discharge rate, with cooling provided by an intercell planar (rectangular cross section) heat pipe. For purposes of comparision, thermocouple measurements were also taken with an Al conduction fin substituting for the heat pipe. The Al fin and heat pipe were cooled, by room temperature forced air. Thermally insulated cells were also cycled at the same rates. Cell case temperatures were measured during cycling, and a maximum of 29^{o} with a 5^{o} thermal excursion was noted with the heat pipe under conditions of thermal equilibrium which were observed after 3 complete cycles. For the Al fin configuration a maximum of 42^{o} with a 7^{o} thermal excursion was obtained near thermal equil. after 5 complete cycles. The insulated configuration yielded a battery case temperature of 83^{o} after 5 cycles, and thermal equil. was never reached. Coulombic efficiency values for the heat pipe cooled battery were several percent greater than 95% which was recorded for the Al fin configuration. The sp. heat of the cells was 0.27 cal/g.^{o}C. From this and the measured values of the total heat generated per cycle, the effectiveness of the heat pipe in removing battery heat was calcd. to be 26% greater than the Al fin at or near equil. It is surmised that the significantly lower operating temperatures produced by the heat pipe should lead to an important lengthening of battery cycle life and an associated reduction of capacity degradation.

71104 SMALL AXIAL TURBINE STAGE COOLING INVESTIGATION

A. Stappenbeck, S. Moskowitz, T. Dalton, H. Watts, and A. Sievers. Final report, April 1971, Rept. No. CW-WR-69-0077, F USAAVLABS-TR-71-14. Contract DAAJ 02-69-C-0064, 209 p., Avail: TAC

The report describes an investigation of advanced cooling concepts for the gas producer axial flow turbine of a small gas turbine engine. These concepts were directed toward minimizing the engine performance penalties, especially at part power, associated with conventional air cooling of the turbine. The initial phase consisted of a conceptual analysis of five stator and five rotor cooling concepts. The coolants for closed systems included liquid metal, high pressure gas, two phase H20, heat pipe (two-phase liquid metal), and superheated steam. Modulated compressor air for transpiration cooling was also studied. To return the heat to the cycle, heat exchangers used in conjunction with the closed coolant systems utilized compressor exit air of fuels. Heat transfer analyses and preliminary designs were conducted on two selected turbine cooling concepts. The concepts selected as the most feasible included the closed systems using liquid metal or high pressure air for the stator and liquid metal or superheated steam for the rotor. Compressor discharge air was used as the heat sink for these systems. The effects of these systems on engine performance were also evaluated.

71105 THERMAL DESIGN OF HEAT PIPE COOLED A-C MOTOR
J.C. Corman and M.A. McLaughlin, ASME Winter Annual Meeting, Washington, D.C., November 28-December 2, 1971, ASME No. 71-WA/HT-14, Avail: TAC

A serious limitation in high power density electric motors results from ineffective transfer of thermal energy from the point of generation to an external location. In a conventional motor, the generated heat is transferred by conduction to the exterior of the motor. At these exterior locations, the heat is dissipated by forced convection to ambient air. Heat pipes can be employed to increase significantly the effectiveness of this energy transport.

A heat pipe cooled A-C induction motor was designed, constructed and tested. Heat pipes were employed in both the rotor and stator to transfer the heat from the point of generation to the ends of the motor. The condenser sections of the rotor heat pipes were used as a fan structure to supply coolant air to the finned condenser sections of both the rotor and stator heat pipes. The test results and an analysis of the thermal system demonstrated the applicability of heat pipes to rotational equipment cooling and the utility of the a priori design procedure.

B. 2 Thermionic and Thermoelectric Converters

71053 CONCEPTUAL DESIGN OF A 150 KWE OUT-OF-CORE NUCLEAR THERMIONIC CONVERTER SYSTEM

James J. Ward, Roland Breitwieser, Richard M. Williams, NASA, Lewis Research Center, Cleveland, Ohio, In: Institute of Electrical and Electronics Engineers, Annual Thermionic Conversion Specialist Conference, 9th, Miami Beach, Fla., Oct. 26-29, 1970, Conference Record. (A71-25856 11-03), New York, Institute of Electrical and Electronics Engineers, Inc., 1970, p. 179-184, 16 refs. Avail:TAC

Nuclear-thermionic systems with the thermionic converters outside the reactor have been re-examined in the perspective of several recent technical advances: new high-temperature, corrosion-resistant, high-strength alloys; high-heat-flux heat pipes; improved thermionic converters; and lightweight, vapor-cooled radiators. These have been combined to yield a new look to the out-of-core approach. A versatile, compact reactor results; insulators are eliminated by the use of heat pipes as electrically resistive elements; and weights are reduced by combining vapor-cooled radiator, structural supports, and current leads into vapor-cooled radiator modules. The over-all design is also highly modular and thus provides high reliability and a reduction in development time and costs.

71054 A 5 kW(e) RADIOISOTOPE THERMIONIC POWER SUPPLY FOR UNMANNED ELECTRIC PROPULSION

W. G. Homeyer, A. J. Gietzen, and C. A. Heath, Gulf General Atomic, Inc., San Diego, Calif., In: Institute of Electrical and Electronics Engineers, Annual Thermionic Conversion Specialist Conference, 9th, Miami Beach, Fla., Oct. 26-29, 1970, Conference Record. (A71-25856 11-03) New York, Institute of Electrical and Electronics Engineers, Inc., 1970, p. 376-381. Contract No. NAS 2-5891. Avail:TAC

The preliminary design of a radioisotope thermionic power supply for unmanned electric propulsion missions to the outer planets is described. In this design, there are 69 independent modules consisting of a thermionic converter, an emitter heat pipe to collect and concentrate heat from the isotope source, and collector and radiator heat pipes to remove heat from the collector and radiate it to space. The 69 modules are electrically connected in a series-parallel network to produce 15 volts at 5 kW(e). The 52 kW(t) of Cm-244 radioisotope is contained in 136 cylindrical capsules which are arranged to form a compact heat source. Heat is transferred from the capsules to the emitter heat pipes by radiation. The heat source is protected by a package of safety equipment to prevent dispersal of the isotope in the event of accidents during launch and ascent. This safety equipment is designed to be jettisoned from the power supply after hyperbolic trajectory is reached and the danger of reentry into the earth's atmosphere has passed. The mass of the 5 kW(e) power supply is 142 kg after jettison of the safety equipment and 426 kg before jettison. A launch escape system to remove the radioisotope power supply from the vicinity of a fire or explosion on the launch pad is estimated to have an additional mass of 290 kg, but can be jettisoned at low altitude and velocity where it will have little effect on the payload capability of the launch vehicle. The most important problems anticipated in the development of such a power supply are in aerospace nuclear safety and in the development of reliable components to meet the mission lifetime requirement of 72,000 hours.

71055 ISOTOPE KILOWATT PROGRAM QUARTERLY PROGRESS REPORT FOR PERIOD ENDING DECEMBER 31, 1970, Oak Ridge National Lab., Tenn., Feb. 1971, (ORNL-TM-3292), Contract W-7405-eng-26, 26 p. Avail:TAC

The organic fluid capsule test system was constructed, the test installation was completed, the system was brought up to temperature, and endurance testing was started at 600°F on December 30, 1970. The heat pipe and associated test equipment for the thermoelectric heat transfer test were fabricated, the test installation was completed, and the shakedown tests were initiated. Some difficulty was experienced with overcooling of the condenser end of the heat pipe during the initial startup, but this was overcome by changing the startup procedure. The heat pipe was started up and operated satisfactorily during the last week of December. Analyses of the relative performance characteristics of iron and nickel heat block-shield assemblies have been completed. The study shows that nickel will be required if advanced thermoelectric materials become available and are to be operated with a hot junction temperature of 1350°F, but for the rest of the systems steel will be satisfactory. Nickel is generally superior to steel, but steel is adequate for the other applications. The cost and delivery time are, of course, much greater for nickel. The 4.10-in. diameter fuel capsule for the $SrTiO_3$ source has been evaluated and a detailed report validating the capsule design with a safety analysis has been prepared.

71077 RESULTS OF STUDIES ON VARIOUS FAST AND THERMAL THERMIONIC REACTOR SYSTEMS
R. Pruschek, S. Dagbjartsson, D. Emendorfer, M. Groll, W. Haug, B. Rohrborn, H. Unger, E. Wolf (Institut fur Kernenergetik Universitat Stuttgart) 1968, 14 p. Second Int. Conf. on Thermionic Electrical Power Generation. Avail: TAC

The results of various studies on five different thermionic reactor systems are reported. Information is given on characteristic data of these devices as the amount of fissile material, power output, specific power, mass of components, total mass etc. Problems of power flattening, long time behaviour, integration of converters to the nuclear heat source as well as specific design features of the following types of thermionic reactors are discussed: 1) moderated incore thermionic reactor (TRIKT), 2) moderated double diode thermionic reactor (DD-TR), 3) fast incore thermionic reactor (SRIKT), 4) fast out-of-core thermionic reactor, emitter heated by heat pipes (WR-TR), 5) fast out-of core thermionic reactor, emitter heated by thermal radiation (SRAKT-WR). Among the concepts considered the moderated incore thermionic reactor system (TRIKT) is the most attractive within a few ten to a few hundreds of kW_{el}. In the lower power range the "Teilthermionikreaktor" (ITR) seems reasonable.

71106 DESIGN AND ANALYSIS OF A CASCADED THERMOELECTRIC GENERATOR

P. Rouklove (California Institute of Technology, Jet Propulsion Lab., Pasadena, California), In: Society of Automotive Engineers, Intersociety Energy Conversion Engineering Conference, Boston, Massachusetts, August 3-5, 1971, Proceedings, p. 611-620, Avail: TAC

Description of the development and construction features of a cascaded generator using silicon-germanium (Si-Ge) thermoelectric elements as a first stage, coupled to a second stage of lead-telluride (Pb-Te) elements. A heat pipe is utilized as the interstage thermal coupling mechanism. The device operates between 1283 K on the hot side of the Si-Ge stage and 464 K on the cold junction of the Pb-Te stage. The design of the complete cascaded generator, including the interstage coupling, heater, and heat rejection system is described, as well as the details of the test equipment. A conversion efficiency of 8% or more at an electrical output of 200 W is predicted.

71107 PERFORMANCE EVALUATION AND LIFE TESTING OF THERMOELECTRIC GENERATORS AT THE JET PROPULSION LABORATORY

Rouklove, P., Truscello, V. (Jet Propulsion Lab., Pasadena, California) Proceedings of the Fourth Intersociety Energy Conversion Engineering Conference, September 22-26, 1969, Washington, D.C., New York, American Institute Chem. Engr. (1969), pp.436-46

Ten generators have been, or are being, evaluated. Generators tested have included those of the SNAP-11 and SNAP-19-type, as well as cylindrical thermoelectric module generator mounted on a heat pipe. Results of testing show that thermoelectric generators are capable of reliable long-time operation and are well suited for long-term space missions.

71108 DYNAMICS OF A POWER SUPPLY WITH A MODERATED THERMIONIC REACTOR.
E. Wolf, V. Speidel, Atomkernenergie Vol. 16, No. 1 1970, p. 19-28 in German, Avail: TAC

Dynamics of a power supply with a moderated thermionic reactor, (Zur Dynamik einer Energieversorgungsanlage mit einem moderieten Incor-Thermionikreaktor); E. Wolf (Universitaet Stuttgart, West Germany), V. Speidel; Atomkernenergie v 16 n 1 1970 p. 19-28. The dynamic behavior of a power supply for spacecraft comprising a moderated incore thermionic reactor (ITR) and a heat pipe radiator is studied from a self-stabilizing point of view. Under certain conditions the heat transfer characteristics of the thermionic converters show a statically unstable region located near the maximum power working point of the converters. If the converter parameters reach that region there will be a large fuel temperature rise which may result in a destruction of the thermionic fuel elements. The time lapse of this kind of fuel burnout is discussed.

B.3 Aerospace Oriented Applications

71056 THERMOPHYSICS, APPLICATIONS TO THERMAL DESIGN OF SPACECRAFT
J. T. Bevans, Academic Press, Inc., New York, 1970, 580 p. A collection of technical papers drawn from the AIAA 4th Thermophysics Conf, June 16-18, 1969, and from the AIAA 7th Aerospace Sciences Meeting, Jan 20-22, 1969, (Progr. in Astronaut. and Aeronaut. v. 23)

The twenty-six papers in this collection are grouped under the following categories—experimental thermophysical properties, analytical predictions of thermophysical properties, and thermal design of spacecraft systems. The last section is obviously devoted to applications engineering problems and, among the more significant, are two papers on heat pipes.

71057 SPACE STATION DESIGN CONCEPTS
M. N. Tawil and A. A. Ferrara, Grumman Aerospace Corp., Bethpage, N. Y., American Institute of Aeronautics and Astronautics, Thermophysics Conference, 6th, Tullahoma, Tenn., Apr. 26-28, 1971, Paper 71-431, 14 p., 5 refs., Contract No. NAS 9-10436 Avail:TAC

Optimum thermal control concept for the manned Space Station project is studied in terms of maximum reliability, minimum weight and power requirements, and elimination of spacecraft attitude constraints imposed by temperature limitations. Two design concepts are considered. The first is a heat-pipe concept which exclusively uses heat pipes throughout the spacecraft for thermal measurement. The second is a semipassive/air-cooled concept which rejects a sizable heat load passively through the insulation with forced air cooling to control cabin and equipment temperatures. The two concepts are compared with the conventional fluid-loop concept. Additionally, a brief discussion of the baseline configurations used for this study and the mission profile is presented. Analyses show that both concepts are feasible and temperatures can be maintained during both the low and high heat load thermal environments.

71078 HEAT PIPES FOR THERMIONIC SPACE POWER SUPPLIES
C. A. Busse (Third International Conference of Space Technology, 3-8 May 1971). 12 p. Avail: TAC

Heat pipes for thermionic space power supplies have to operate essentially in two different temperature ranges: around 700°C (collector cooling) and above 1500°C (emitter heating). Axial heat transfer capabilities of 7 respectively 15 kw/cm^2 have been obtained in these temperature ranges. Still much higher heat flux densities are theoretically possible. For collector heat pipes there is a rather wide variety of compatible material combinations. In heat pipes operating at emitter temperature corrosion plays an important role; nevertheless there is a number of material combinations, which under sufficiently clean conditions show good compatibility. For example, at 1600°C W-26Re/Li is a promising heat pipe system, which has already been operated without failure for 10,000 hours.

71079 ISOTHERMAL COVER WITH THERMAL RESERVOIRS
National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Ala., Ambrose W. Byrd, Inventor (To NASA). Issued 22 Dec. 1970 (Filed 30 Jul. 1969) 5 p. Cl. 165-105; Cl. 165-104; Cl. 165-133; Cl. 244-1; Cl. 219-378; Cl. 219-530; Int. Cl. F28d 15/00 (NASA-CASE-MFS-20355; US-Patent-3,548,930; U.S.-Patent-Appl.-SN-845974)
Avail: TAC

An isothermal cover for a spacecraft is reported. The device is a double walled cylinder enclosing a number of containers of fusible material, mounted on struts inside the walls of the cylinder, for use as heat reservoirs. The inside surfaces of the cylinder and the outside surfaces of the containers and struts are covered with a wicking material. The cavity of the double walled cylinder also contains a heat transfer fluid. The device functions as a heat pipe in transferring heat from its sunlit to its other (dark) side. The heat reservoirs store heat when the device is in sunlight and return the heat to the system when the device is in darkness.

71080 A LOW-POWER THERMIONIC REACTOR WITH EXTERNAL CONVERTERS AND HEAT-PIPE-COOLED COLLECTORS.
S. Dagbjartsson, M. Groll, P. Zimmermann (Institut fur Kernenergetik Universitat Stuttgart) Jan. 1969, 4 p. (In German)
Avail: TAC

The design of a fast thermionic reactor as a power source for spacecraft is presented. Planar cesium converters are arranged around the cylindrical core. The emitters are heated by heat radiation from the core surface. The collectors are cooled by means of heat pipes. A beryllium reflector is attached to the converter section and leads to the desired power flattening in the axial direction. A part of the radial reflector is used for reactor control.

The design of the power plant and some problems of the series-parallel connections of the converters will be discussed. A survey of methods and results of the computations is given. The plant can be operated in a region below 15 kW. The respective mass is about 260 kg (shielding not included). The plant is characterized by simple structure and high reliability.

71081 STUDY OF APPLICATIONS OF HEAT PIPES TO TEMPERATURE CONTROL FOR EUROPEAN METEOROLOGICAL SATELLITE
Technische Hochschule Stuttgart (West Germany). Inst. fuer Kernenergetik, Mar. 1971, 53 p., refs. (contract Estec-1048/70-HP). Avail: TAC

Heat pipes for meteorological satellite temperature control are studied. Life tests were performed on the stainless steel and copper heat pipes with acetone, ethyl and methyl alcohols as heat carriers. It is concluded that stationary and periodical tests should be carried out in order to study the corrosion mechanism, formation of gas buffers, and endurance limit of the welds.

71082 EXPERIMENTAL HIGH PERFORMANCE HEAT PIPES FOR THE OAO-C SPACECRAFT.
Walter Bienert, Edward Kroliczek. (Dynatherm Corp., Cockeysville, Md.) American Society of Mechanical Engineers, Society of Automotive Engineers, and American Institute of Aeronautics and Astronautics, Life Support and Environmental Control Conference, San Francisco, California, July 12-14, 1971, ASME Paper 71-Av-26. 11 p. 6 refs. Avail: TAC

Two circular heat pipes with an arterial wick were developed, featuring a high-heat transport capability combined with insensitivity to gravity and low overall thermal resistance. They will have a dual function on the spacecraft - i.e., to isothermalize its structure and to evaluate arterial heat pipes in a flight experiment. The heat pipes were laboratory tested in both the arterial and conventional mode, and all performance criteria were met. Some difficulties were encountered, however, in reliably priming the artery under all conditions in the laboratory. In parallel with the development of the flight hardware, pressure qualification tests of aluminum-ammonia heat pipe samples were conducted, and a 3000-hr life test was completed.

71083 THERMAL CONTROL SYSTEMS DESIGN FOR SPACE STATION
M.N. Tawil and A.A. Ferrara (Grumman Aerospace Corp., Bethpage, N.Y.) American Society of Mechanical Engineers, Society of Automotive Engineers, and American Institute of Aeronautics and Astronautics, Life Support and Environmental Control Conference, San Francisco, Calif., July 12-14, 1971, ASME Paper 71-Av-36. 20 p., 8 refs. Avail: TAC

An investigation, made to formulate the evaluate alternative concepts for space station thermal control systems, resulted in two advanced systems being designed and compared to the present pumped loop system. The advanced concepts are the air-cooled semipassive system, which features rejection of a large percentage of the load through the outer skin, and the heat pipe system, which incorporates heat pipes for every thermal control function. Both advanced systems show significant weight and power consumption advantage over the state-of-the-art pumped loop system. Thermal analyses demonstrated that all of the systems were capable of meeting the performance requirements under all design conditions. The design details presented in this paper demonstrate that advanced system hardware may be used to realize a potential 30 per cent weight savings over present techniques.

71109 OPTIMIZATION OF A SHIELD FOR A HEAT PIPE COOLED FAST REACTOR DESIGNED AS A NUCLEAR ELECTRIC SPACE POWER PLANT
Engle, W.W. Jr.; Childs, R.L.; Mynatt, R.F.; Abbott, Lorraine S. (Oak Ridge National Lab, Tennessee) June 15, 1971, Contract W-7405-eng-26, 41 p. (ORNL-TM-3449) 13 refs., Avail: TAC

A reactor shield optimization procedure based on the ASOP shield optimization computer code and the DOT radiation transport code was used to determine a minimum weight shield for a small fast reactor designed for a space nuclear electric power plant. The reactor, cylindircal in shape, is fueled with un and cooled by liquid K circulating through a matrix of stainless steel heat pipes embedded in the core; the design power is 450 kW(t). The surrounding shield is typically asymmetric, having the overall shape of a truncated 90-degree cone whose thick base is positioned between one end of the reactor and the crew compartment. The heat pipes emerge from the opposite end of the reactor, penetrating through the apex of the shield. The dose constraints are three mrem/hr at all 100-ft radii falling within the shadow cast by the base of the cone and 300 mrem/hr at all other 100-ft. radii. The optimized shield consists of alternate layers of W and LiH, the thick bottom section extending out to a radius of 112 cm and the tapered side decreasing to a radius of 89 cm. The top heat pipe shield region consists of a 59-cm-thick inner layer of a stainless-steel-B_4C mixture and a 30.5-cm-thick outer layer of a BeO-B_4C mixture. The total shield weight is 25,589 lb. A partially optimized shield having a 45-degree cone angle and a higher dose contraint for positions outside the cone shadow (100 rem/hr) has a total weight of 14,708 lb. These shield weights include an allocation of 3.5 vol% of stainless structure in the LiH regions.

71110 POTASSIUM RANKINE CYCLE VAPOR CHAMBER (HEAT PIPE) RADIATOR STUDY

Ellsworth E. Gerrels, Robert E. Killem (General Electric Company, Philadelphia, Pennsylvania), NASA Contractor Report (NASA CR-1866), September, 1971, 230 p. (GESP-7047) Avail: TAC

A structurally integrated vapor chamber fin (heat pipe) radiator is defined and evaluated as a potential candidate for rejecting waste heat from the potassium Rankine cycle powerplant. Several vapor chamber fin geometries, using stainless steel construction are evaluated and an optimum is selected. A comparison is made with an operationally equivalent conduction fin radiator. Both radiators employ NaK-78 in the primary coolant loop. In addition, the Vapor Chamber fin (VCF) radiator utilizes sodium in the vapor chambers. Preliminary designs are developed for the conduction fin and VCF design. Performance tests on a single vapor chamber were conducted to verify the VCF design. A comparison shows the conduction fin radiator easier to fabricate, but heavier in weight, particularly as meteoroid protection requirements become more stringent. While the analysis was performed assuming the potassium Rankine cycle powerplant, the results are equally applicable to any system radiating heat to space in the 900° to 1400°F temperature range.

71111 SPLIT-CORE HEAT PIPE REACTORS FOR OUT-OF-PILE THERMIONIC POWER SYSTEMS
G. Niederauer, E. Lantz, and R. Breitweiser, NASA Lewis Research Center, Cleveland, Ohio, 1971, 8 p., Presented at the American Nuclear Society Winter Meeting, Miami Beach, Florida, October 17-21, 1971, Avail: TAC

The concept of splitting a heat pipe reactor for out-of-core thermionics into two identical halves and using the resulting center gap for reactivity control is described. Short Li-7-W reactor heat pipes penetrate the axial reflectors and form a heat exchanger with long heat pipes which wind through the shield to the thermionic diodes. With one reactor half anchored to the shield, the other is attached to a long arm with a pivot behind the shield and swings through a small arc for reactivity control. A safety shim prevents large reactivity inputs, and fueled control arm drive shaft acts as a power stabilizer. Reactors fueled with U-235C and with U-233C were studied.

B. 4 Nuclear Systems

71058 NUCLEAR POWER PLANT FOR A SPACE STATION
Peter Fiebelmann, Helmut Neu, Umberto Buzzi, to EURATOM. British Patent 1,220,554. 27 Jan. 1971, Priority date 24 May 1968, Germany

Heat Pipes—design parameters for thermionic reactor shielding cooling.

Nuclear Auxiliary Power Systems—design parameters of thermionic reactor system with heat pipe cooling of radiation shield.

Shielding—cooling system for thermionic reactor, description of heat pipe for.

71059 NUCLEAR POWER PLANT FOR A SPACE STATION
Peter Fiebelmann, Helmut Neu, Umberto Buzzi, to EURATOM. British Patent 1,220,644. 27 Jan 1971, Priority date 24 May 1968, Germany

Heat Pipes—protection of, description of radiator plates for.

Nuclear Auxiliary Power Systems—design of thermionic reactor system with heat pipe protection by radiator plate.

Radiator—design parameter of plate type, for protection of heat pipes.

71060 NUCLEAR REACTOR WITH HEAT PIPES
Helmut Neu, Peter Fiebelmann, to EURATOM. British patent 1,220,553. 27 Jan. 1971. Priority date 21 May 1968, Germany.

Heat Pipes—design parameters of dual crossed axes, for thermionic reactors

Nuclear Auxiliary Systems—core configuration for thermionic reactor with dual crossed-axis heat pipe system.

71061 APPLICATIONS OF HEAT PIPES TO NUCLEAR REACTOR ENGINEERING
Monte Bryce Parker, Ames, Iowa; Iowa State Univ. 1970. 86p.
University Microfilms Order No. 70-25,816.

A feasibility study was made of the use of heat pipes as reactivity control devices for a nuclear reactor. The heat pipes contain uranium tetrafloride as the heat pipe working fluid. The evaporator section is within the reactor and the condenser section is outside the reactor. The reactor model used is based on a reactor used in rockets such as Nerva. Equations are derived relating the neutron flux and coolant temperature to the mass of fuel in the heat pipe evaporator section. The reactivity of the mass changes of the fuel is determined using a perturbation analysis. Other feedback effects are then added to the system and the time dependent behavior of the neutron density is determined for step and ramp reactivity inputs.

71062 HEAT PIPES FOR RECOVERY OF TRITIUM IN THERMONUCLEAR REACTOR BLANKETS
R. W. Werner, California Univ., Livermore. Lawrence Radiation Lab, 18 Mar. 1970, 7 p. refs., Presented at 5th Ann. Intersoc. Energy Conversion Eng. Conf., Las Vegas, Nev., 21-25 Sep. 1970 Sponsored by AEC, (UCRL-72329; CONF-700912-9)Avail:TAC

Controlled thermonuclear reactors, using deuterium—tritium as a fuel for the fusion reaction, require a means of regenerating tritium so that cycle continuity is maintained. A unique way for satisfying the tritium needs is suggested. It is proposed that heat pipes using sodium as a working fluid be used in tritium transporters in the blanket structure of a fusion reactor. The tritium produced by the reactions in the lithium moderator of the blanket would be diffused through the heat-pipe wall and transported within the heat-pipe body and then processed for recycling. Heat pipes are explained as heat-transfer devices and as gas handlers in a fusion reactor environment.

71084 HEAT PIPES AS A MEANS OF ENERGY REMOVAL FROM THERMONUCLEAR REACTOR VACUUM WALLS
R.W. Werner (California Univ., Livermore, Lawrence Radiation Lab.) July 24, 1968, 13 p. (UCID-15386). Avail: TAC

Incident flux limits imposed by heat transfer considerations on vacuum walls of thermonuclear reactors are discussed. The use of heat pipes for energy removal indicates that fluxes of $\sim$500 w/cm^2 can be achieved as compared with $\sim$250 w/cm^2 for conventional cooling. Limiting conditions for heat pipes are considered. Lithium is shown to be a good choice as a heat pipe fluid with sodium second.

71112 HEAT PIPE COOLED REACTOR AND HEAT EXCHANGER FOR BRAYTON-CYCLE POWER SYSTEMS
T.G. Fran, G.M. Grover, R.C. Anderson, C.D. Sutherland and E.O. Swickard (Los Alamos Scientific Laboratory, Los Alamos, New Mexico) In: Society of Automotive Engineers, Intersociety Energy Conversion Engineering Conference, Boston, Massachusetts, August 3-5, 1971, p. 472-477, 5 refs., Avail: TAC

Description of a shielded reactor and heat exchanger design which can be coupled with three 10-to-15-kWe Brayton B turbine generator units to provide a 30-to-40-kWe space power supply. The system is characterized by low weight and highly reliable and redundant components. Heat transfer from the reactor to the heat exchangers is accomplished by heat pipes in such a way that isolated failures of heat pipes, core cladding, the reactor vessel, or combinations thereof can be tolerated without necessitating shutdown or resulting in significantly decreased longevity of the reactor. Space for anticipated fuel swelling is easily provided and fission products are doubly contained. Multiple heat exchangers and Brayton-cycle engines provide additional system redundancy. No extrapolations of current technology have been assumed. Extended lifetimes of the order of five years should be readily attainable. The reactor concept is amenable to straighforward modification to obtain higher temperatures and higher power levels.

B. 5 Electronic Applications

71085 HIGH POWER LINEAR BEAM TUBE DEVICES
P. Guenard, Journal of Microwave Power, Vol. 5, Dec. 1970, p. 261-267, 7 refs. Avail: TAC

As compared to high power tubes for satellite-borne communications transmitters, tubes for a space power station have no requirements on bandwidth and linearity characteristics. For this reason, the travelling wave tubes, which are interesting for communications because of their ability to transmit wide frequency bands, would very likely be discarded for power generation, because of their lower efficiency, which would require a rather complicated depressed collector. Among the various types of klystrons, the electrostatically focussed tube would bring the advantage of a lower weight, but this tube has to be improved to reach the efficiencies which have been demonstrated for magnetically focussed tubes. The discussion of a figure of merit in comparing various types of tubes for this particular application shows the importance, to reduce the overall weight, of operating the collector at as high a temperature as possible. This could be done with klystrons, where the heat dissipating electrode is well separated from the gun and the microwave structure. This high temperature operation of the heat radiators, together with a new technology based on an open structure and the extensive use of heat pipes should put the klystron in a good competitive position for the equipment of space power stations.

71086 DEVELOPMENT OF A 250 AMPERE TRANSCALENT RECTIFIER
S.W. Kessler, RCA Electronic Components, Lancaster, Pa.
Rept. No. 3, 1 June-31 Dec 70, Feb 71, 25 p. Contract DAAK02-69-C-0609. Avail: TAC

During the investigation the water was frozen and its flow to the evaporator limited by the rate at which ice in the wick could be melted. External thermocouples on the heat pipes and the forward voltage of the junction were monitored to determine the transient thermal impedance of the transcalent rectifiers. The experiment was conducted by applying an average current of 250 amperes to the transcalent rectifiers in an ambient of -25C. The data was analyzed with respect to the thawing of the heat pipes. Two transcalent rectifiers were successfully cycled 55 times at their rated current before discontinuing the test. Each cycle was of sufficient length for the rectifiers to be in thermal equilibrium with their environment and consisted of 15 minutes on -15 minutes off. A summary of the 400 ampere RMS transcalent thyristor design which was initiated during the performance of this contract. The silicon chip design incorporates an insulated emitter gate junction structure which will be located inside the wall of the heat pipe so that the periphery of this junction can be cooled.

C. HEAT PIPE THEORY

C. 1 General Theory

71046 A SPACE APPLICATION OF A CRYOGENIC HEAT PIPE
Robert A. Callens, Science and Technology Accomplishments, 1969, NASA SP-251, p. 244-248, Avail:TAC

The paper describes a cryogenic heat pipe proposed as the thermal link between the central refrigerator and the remotely located cryogenically cooled sensor platforms of a spacecraft. The heat pipes are part of the integrated cryogenic isotope cooling engine (ICICLE). The results of calculations using a theoretical model are compared with experimental data.

71063 STEADY STATE AND DYNAMIC BEHAVIOR OF HEAT PIPES (DAS STATIONARE UND INSTATIONARE BETRIEBSVERHALTEN VON WARMEROHREN)
M.Groll and P. Zimmermann, Stuttgart, Universitat, Stuttgart, West Germany Waerme- und Stoffuebertragung, vol. 4, no. 1, 1971, p. 39-47, 27 refs. In German, Avail:TAC

Heat pipes are construction elements with an extremely high heat transport capability. The physical principles and mathematical methods for describing the steady state and the dynamic behavior of heat pipes are presented. The steady state performance is described by a pressure balance for the heat pipe. The dynamic behavior with fully developed vapor flow in the heat pipe is described with sufficient accuracy by a heat balance. Some of the many examples of heat pipe applications will be presented. The dynamic behavior for different variations of the heat input will be discussed and special regard is given to the performance limitations.

71064 APPLYING HEAT PIPES TO THERMAL PROBLEMS
W. E. Harbaugh, G. Y. Eastman, Heating Piping and Air Conditioning, Oct. 1970, p. 92-96, Avail:TAC

The article briefly describes the principle of operation of a heat pipe emphasizing its basic components and material requirements. Calculated performances are listed for heat pipes with mercury, sodium, lithium, ammonia and water as heat transfer media as a function of operating temperature. The operating temperature ranges and the corresponding maximum power density are presented. The effect of gravity on the operation of a heat pipe is shown for different wick structures. Some limitation to the heat pipe operation such as maximum energy transport, maximum power density and sonic velocity of the vapor are listed. The results of heat pipe life tests for heat pipes of different materials using different heat transfer fluids are presented.

71065 PERFORMANCE CHARACTERISTICS OF CYLINDRICAL HEAT PIPES FOR NUCLEAR ELECTRIC SPACE AND UNDERSEA POWER PLANTS
M. E. LaVerne, Oak Ridge National Lab, Tenn., Jan. 1971, 75 p. Refs., (Contract W-7405-ENG-26) (ORNL-TM-2803) Avail:TAC

A preliminary investigation was made of the performance characteristics of cylindrical heat pipes with a view toward their incorporation as heat transport devices in nuclear electric space and undersea power plants, where reliable unattended operation is of prime importance. The basic operating principles of the heat pipe are summarized, together with an enumeration of the pertinent thermodynamic and transport fluid properties and a brief discussion of each. A number of capillary structures of both the simple and composite type is described and some of the advantages and disadvantages are delineated. The readily available heat pipe operating lifetime data are reviewed and are summarized in tabular form. The data show that the heat pipe is capable of the long-term reliability required for unattended operation. The theoretical bases for predicting several of the inherent heat pipe performance limits are reviewed and the resulting predictions compared with experimental data. The optimization of heat pipe geometry with respect to performance is shown for the situation where heat pipe output is not limited by compressibility or entrainment effects. The effects of several geometric and fluid parameters are examined, primarily by means of the theoretical relations previously obtained.

71087 HEAT PIPE THEORY
J.L. Watts, M.A. Janssen (California Univ., Livermore, Lawrence Radiation Lab), April 18, 1966, 22 p. (UCID-15690). Avail: TAC

The Grover "heat pipe" is a recent innovation which appears to have promising applications in space power plant designs, particularly for a thermionic system. Due to the complexity of the hydrodynamics involved in heat pipe operation, the theory is semi-empirical; and although a number of heat pipes have been successfully constructed and operated, little has been reported along the line of comparing theory and experiment. This note summarizes the theory of heat pipes as it presently exists, the main objective being the presentation of some working formulae and relationships for use in future system studies.

71088 OPERATING PRINCIPLES OF HEAT PIPES
J.E. Kemme, Los Alamos Scientific Lab, New Mexico, Proc. of 4th Intersociety Energy Conversion Eng. Conf., Washington, D.C., Sept. 22-26, 1969, p. 14. Avail: By Author Only.

71089 TRANSIENT PERFORMANCE OF ELECTRICAL FEEDBACK-CONTROLLED VARIABLE-CONDUCTANCE HEAT PIPES
Walter B. Bienert, Patrick J. Brennan (Dynatherm Corp., Cockeysville, Md.) American Society of Mechanical Engineers, Society of Automotive Engineers and American Institute of Aeronautics and Astronautics, Life Support and Environmental Control Conference, San Francisco, California, July 12-14, 1971, ASME Paper 71-Av-27, 9p. Avail: TAC

The authors investigated the effects of various system parameters on the transient response of a heat source whose temperature is regulated by an electrical feedback-controlled variable-conductance heat pipe. A closed-form analytic solution which can be used to evaluate the transient performance and provide preliminary design data is presented. Results obtained with an experimental model of an electrical feedback-controlled heat pipe are discussed and correlated using the closed-form solution. An optimum design of such a system depends on a trade-off between steady-state and transient considerations.

71090 THERMAL CONTROL OF ATS F AND G.
Robert J. Eby, William H. Kelly, and Robert D. Karam (Fairchild Hiller Corp., Space and Electronics Systems Div., Germantown, Md.). American Society of Mechanical Engineers, Society of Automotive Engineers, and American Institute of Aeronautics and Astronautics, Life Support and Environmental Control Conference, San Francisco, Calif., July 12-14, 1971, ASME Paper 71-Av-28, 14 p. 10 refs. Avail: TAC

This paper presents Applications Technology Satellite (ATS) F and G thermal requirements, design and analysis. The analysis may be broken down into three general categories: heat pipe, louver, and system. The heat-pipe analysis includes design equations and curves, generated to determine optimum design, and culminates in a heat-transport capability vs transport-distance curve. The louver analysis outlines methods used to determine louver heat-rejection capability for various operating modes, orbital conditions, and solar heat inputs. A multinode thermal model that is described was used to obtain detailed temperature maps for structure and components.

71113 DYNAMIC ANALYSIS OF SATELLITE HEAT PIPE FLUID ENERGY DISSIPATION
E. A. O'Hern, V. Baddeley, and J. E. Pakowski (North American Rockwell Corporation, Space Division, Downey, California) International Astronautical Federation, International Astronautical Congress, 22nd Brussles, Belgium, September 20-25, 1971, Paper 21 p. Avail: TAC

A described mathematical heat pipe model is shown to provide excellent agreement with observed satellite dynamic characteristics and to confirm the estimated stability of a planned rescue approach configuration. It is felt that this model is sufficiently broad to support other heat pipe applications having varying pipe numbers and dimensions, fluid masses, geometries, and satellite inertial and dynamic parameters.

71114 THEORY AND DESIGN OF VARIABLE CONDUCTANCE HEAT PIPES: CONTROL TECHNIQUES
B.D. Marcus, TRW Systems Group, Research Report No. 2 July 1971, Rept. No. 13111-6027-R0-00, Contract No. NASA 2-5503, Avail: TAC

The second report on the research effort on a variable conductance heat pipe for spacecraft thermal control deals with theory and design practice relating to heat pipe control.

Most attention is given to passive gas-controlled heat pipes, be they cold or hot, wicked or non-wicked reservoir designs. However, for the sake of completeness, the report also deals briefly with active heated reservoir and feedback controlled systems since these will likely play an important role in spacecraft thermal control.

In addition, the subject matter includes discussions on other control schemes including (1) liquid flow control, (2) vapor flow control, and (3) the use of excess working fluid (rather than non-condensible gas) to effect condenser area variations.

71115 THEORY OF TWO COMPONENT HEAT PIPES
C.L. Tien, A.R. Rohani, ASME Winter Annual Meeting, Washington, D.C., November 28-December 2, 1971, ASME No. 71-WA/HT-30, Avail: TAC

A theoretical framework for predicting the steady-state operational characteristics of two-component heat pipes is established. The laws of conservation of mass and energy as well as thermodynamic phase equilibrium relations are applied to the system and the governing relations between the various system parameters are specified. Measurements of the operational characteristics of a water-ethanol heat pipe indicate that complete separation into two pure components did not occur in any of the experiments. The observed degrees of separation and other operational characteristics agree well with the predictions.

71116 VARIABLE VAPOR VOLUME HEAT PIPES
R. Werner, (Lawrence Radiation Laboratory, University of California, Livermore), UCID-15621, August 9. 1966,

8 p., Avail: TAC

Design of a heat pipe which provides for a vapor volume which changes or adjusts as a function of input power is discussed. An illustrative example using steam is provided. The heat pipe as a temperature transducer is suggested.

71117 DYNAMIC BEHAVIOR OF HEAT PIPES
Zimmerman, Peter (Stuttgart, Germany) Forsch. Ingenieurw, 1971, 37 (2), p. 43-47, In German, Avail: TAC

Based on a qualitative discussion of startup behavior of heat pipes with frozen heat carriers, a model was developed for describing this operational period. Typical startup behavior of heat pipes is discussed.

C. 2 Heat Transfer

71091 HEAT AND MASS TRANSFER IN THE VICINITY OF THE VAPOR-GAS FRONT IN THE GAS LOADED HEAT PIPE
D.K. Edwards, B.D. Marcus (TRW Systems Group, Redondo Beach, Calif., Materials Science Dept.) Contract NAS2-5503, NASA-CR-114300, Jan. 1971, 35 p. refs. Avail: TAC

An analysis is presented to axially conducting gas controlled heat pipes leading to a predictive capability for the heat and mass transfer along the heat pipe. In particular, it was found that axial heat conduction is of much greater importance than axial mass diffusion in establishing the wall temperature profiles and condenser heat transfer characteristics of gas loaded heat pipes. However, mass diffusion and, consequently, the choice of working fluid and control gas are of considerable importance in establishing the diffusion freeze-out rate if the potential exists for freezing of vapor which penetrates the gas-blocked portion of the condenser. It is believed that the analysis and associated computer program are useful tools for designing gas loaded heat pipes.

71118 MEASUREMENT OF THE MAXIMUM AXIAL HEAT FLUX OF A SODIUM OR POTASSIUM HEAT PIPE
Pawlowski, Peter H. (Heidelberg, Germany) Forsch.Ingenieurw, 1971, 37 (2), p. 47-51, In German, Avail: TAC

The maximum axial heat fluxes of a heat pipe with Na or K as working fluid have been measured as a function of operating temperature and on the lift height. The transported heat was transferred to cooling water via a gas gap, the gas pressure of which could be varied. The theoretical heat fluxes have been computed according to existing calculation methods and have been compared with experimental results. Design calculation methods were found for dimensioning of heat pipes.

71119 SONIC LIMIT IN SODIUM HEAT PIPES.
E.K. Levy and S.F. Chou, ASME Winter Annual Meeting, Washington, D.C., November 28-December 2, 1971, ASME No. 71-WA/HT-11, Avail: TAC

The results of an analytical study of the vapor dissociation-recombination and homogeneous vapor condensation phenomena in sodium heat pipes are described. It is shown that neither the dissociation-recombination reaction nor the vapor condensation process has much of an influence on the sonic limit heat transfer rate. The single most important factor is shown to be the wall shear stress in the heat pipe vapor passage. The friction effects control the location of the sonic point, determine if the flow in the condenser section will be subsonic or supersonic, and decrease the sonic limit heat transfer rate to values which can be substantially lower than those which are predicted from inviscid analyses.

71120 THEORETICAL INVESTIGATIONS OF HYDROGEN, NITROGEN, AND OXYGEN HOMOGENEOUS AND ANNULAR WICK HEAT PIPES
Gerard Paulvis and Sidney B. Lang, ASME Winter Annual Meeting, Washington, D.C., November 28 - December 2, 1971, ASME No. 71-WA/HT-13, Avail: TAC

In any heat pipe, the capillary pressure developed at the liquid-vapour interface balances the sum of the various pressure drops throughout the pipe. This study analyzes the different contributions to the pressure drop for both homogeneous wick and annular wick heat pipes operating at low temperatures. The pressure drop in the wick structure is of primary importance for a homogeneous wick heat pipe. The heat transfer capacity of an annular wick heat pipe, in addition, is strongly affected by the interphase pressure drop due to non-zero evaporation and condensation rates at the liquid-vapour interfaces. Theoretical heat transfer rates as functions of the vapour temperature have been computed for both homogeneous and annular wick structures of heat pipes utilizing hydrogen, nitrogen, and oxygen as working fluids. The heat transfer capacity of the annular wick design is more than an order of magnitude higher than that of the corresponding homogeneous wick design.

71121 SURFACE HEAT FLUX FOR INCIPIENT BOILING IN LIQUID METAL HEAT PIPES
Calvin C. Silverstein, Nuclear Technology, Vol. 12, September 1971, p. 56-62, 12 refs., Avail: TAC

Conditions required for incipient boiling in liquid metal heat pipes are examined. It is shown that the heat flux for boiling in heat pipes can be larger than that for pool boiling if thin capillary wicks are used with low fricitional resistance to liquid flow in the axial direction. Methods for calculating the heat flux for incipient boiling in heat pipes are derived. Data on nucleation site radii and interface heat transfer coefficients, needed for heat flux calculations, are available. An upper limit of 3 to 7 microns is determined for the nucleation site radius in sodium heat pipes.

C. 3 CONDENSATION AND EVAPORATION

71122 BOILING LIMIT IN ALKALI LIQUID METAL HEAT PIPES
Calvin C. Silverstein, ASME Winter Annual Meeting, Washington, D.C., November 28-December 2, 1971, ASME No. 71-WA/HT-10, Avail: TAC

The heat transport rate at which boiling is initiated in alkali liquid metal heat pipes is examined. Expressions are developed for the wick temperature drop necessary for the inception of boiling, the associated surface heat flux, and the associated axial heat flux. It is shown that the wick temperature drop for incipient boiling depends on the radius of curvature at the liquid-vapor interface as well as on the radius of vapor bubble nucleation sites, and that the heat flux at incipient boiling is in addition a function of heat pipe geometry. Information from which the boiling limit can be calculated is given for sodium, potassium, and cesium heat pipes over the temperature range of 1300 to 1700 F.

71123 STEADY AND MAXIMUM EVAPORATION FROM SCREEN WICKS
R.A. Seban, A. Abhat, ASME Winter Annual Meeting, Washington, D.C., November 28-December 2, 1971, ASME No. 71-WA/HT-12, Avail: TAC

Heat transfer results are presented, for water at pressures near atmospheric in wicks formed of layers of stainless steel screen, both for complete submergence and for the evaporation into a surrounding vapor that occurs in a heat pipe. Maximum rates of evaporation are found and the "static rise" and permeability inferred therefrom are compared to values deduced from isothermal dynamical performance of the wick. Some results for evaporation performance and maximum evaporation at lower pressures are included.

71124 VAPORIZATION FROM CAPILLARY WICK STRUCTURES
J.C. Corman, G.E. Walmet, ASME - AICHE Heat Transfer Conference, Tulsa, Oklahoma, August 15-18, 1971, 8 p., ASME No. 71-HT-35, Avail: TAC

In a vaporization system, coolant can be directed to specific locations by employing capillary flow produced by a wick structure. This flow control can augment the heat transfer procedure and produce a more effective total system. The combined experimental and analytical study presented herein facilitates the understanding of the fluid and heat transport phenomena necessary for the utilization of wick vaporization.

The system under study consisted of the capillary flow of a saturated liquid through a wick structure. As the liquid was "fed" through the wick, heat was uniformly applied beneath it, causing vaporization. Data was taken for several different wick configurations. Each wick was tested throughout a range of saturation pressures for varying wick thicknesses. The data for wick structures operating with non-metallic working fluids (water, freons, etc.) indicates that vaporization heat transfer coefficients as high or higher than those for smooth surface pool boiling are obtainable.

The experimental results define the thermal resistance of the vaporization phenomena and the dry-out point or limit of the operating heat flux range. An analysis is presented and experimentally verified which allows the dry-out point to be determined for thin wick structures.

71125 EXPERIMENTAL INVESTIGATIONS ON CAPILLARY EVAPORATION COOLING WITH WATER AS THE WORKING FLUID

Quast, Armin (Brunswick, Germany) Forsch. Ingenieurw, 1971, 37 (2), p. 52-55 in German, Avail: TAC

The properties of several capillary structures for heat pipes and capillary evaporation cooling were investigated in open air at 100^{o}. Heat flux ds.$\leq$ 70 W/cm^2 were obtained. No change in the mechanism of evaporation was caused by slanting the heating surface even if the vapor flowed off in the direction of gravity. An experimental circulating unit for evaporation cooling gave satisfactory results, however, only maximum loads of 20 W/cm^2 could be achieved on the heating surface.

C.4 Fluid Flow

71067 EFFECTS OF INTERPHASE TEMPERATURE DIFFERENCES AND WALL FRICTION IN HIGH-TEMPERATURE HEAT PIPES

Peter M. Sockol, NASA, Lewis Research Center, Cleveland, Ohio, Washington Apr. 1971, 22 p. refs. (NASA-TM-X-2268; E-6126)

Avail:TAC

From the analysis of a simple evaporation-heat-transfer system it is shown that the temperature drop required by the second law of thermodynamics occurs at the liquid-vapor interfaces. The temperature drop is estimated for conditions comparable to those in a 30-kW, 1800 K lithium heat pipe. A simple one-dimensional treatment of the fluid dynamics in a high-temperature heat pipe is used to predict pressure drops in such a pipe. The effects of evaporation and condensation on wall friction in turbulent flow are included in the analysis. The additional friction due to condensation is shown to reduce the pressure recovery by a factor of 2. Detailed calculations are presented for two 1800 K lithium heat pipes.

71068 THEORY AND DESIGN OF VARIABLE CONDUCTANCE HEAT PIPES — HYDRODYNAMICS AND HEAT TRANSFER

B. D. Marcus, TRW Systems Group, research rept. no. 1, April 1971, rept. no. 13111-6021-RO-00, Contract NAS2-5503, Avail:TAC

The first report on the research effort on a variable conductance heat pipe for spacecraft thermal control covers the results in the areas of hydrostatics, hydrodynamics, heat transfer, fluid selection and materials compatibility. A literature review is followed by theoretical developments and heat pipe design methods. The compatibility of aluminum, stainless steel, copper and nickel with water, ammonia, methanol, acetone, freon-21, freon-11, and freon-113 is investigated and presented in matrix form. A selected bibliography pertinent to spacecraft control is presented.

71092 INVESTIGATION OF THE HYDRODYNAMICS OF FLUID FLOW IN THE DUCT OF A HEAT PIPE.

Potapov, Iv. F., Tsagi, Uchenye Zapiski, Vol. 1, No. 3, 1970, p. 126-131. 6 refs. In Russian. Avail: TAC

The problem of calculating the flow of an isothermal fluid under the action of capillary forces in a heat pipe under zero-gravity conditions is analyzed. The duct is assumed to be formed by the pipe wall and parallel capillary plates. A relation between the rate of flow and the duct parameters is derived which can be used for selecting the dimensions of capillaries that are optimal with respect to the flow rate.

71126 OPTIMIZATION OF A HEAT PIPE WITH A WICK AND ANNULUS LIQUID FLOW

H. Hwang-Bo and W.E. Hilding, ASME No. 71-HT-V, Avail: TAC

An analytical model has been formulated for the parametric study of liquid flow characteristics in the heat pipe, which consists of a porous tube, a closed outer container tube, and an annulus between them. The analytical model includes the effect of the rate of change of momentum, surface tension forces, the frictional forces in the body of wicking material and at the wall, as well as the axial variation of static pressure supporting the capillary meniscus at the liquid-vapor-wick interface in the vapor passage. The length of the condenser of the heat pipe was optimized as a function of the radial heat flux rate and the ratio of the liquid flow rate in the annulus to that within the wick, W_a/W_w. The effect of pressure loss and recovery in the vapor passage of the heat pipe on the optimum length of condenser was investigated.

71127 INCOMPRESSIBLE LAMINAR VAPOR FLOW IN CYLINDRICAL HEAT PIPES

C.A. Bankston and Hadley J. Smith, ASME Winter Annual Meeting, Washington, D.C., November 28-December 2, 1971, ASME No. 71-WA/HT-15, Avail: TAC

Solutions of the complete two-dimensional Navier-Stokes equations for the steady flow in circular heat pipes with various distributions of evaporation and condensation have been obtained by finite-difference methods. In addition to the numerical results, a new series solution for the slow motion case was obtained which is valid for arbitrary distributions of evaporation and condensation. The series solution confirms the numerical result in the limit of low Reynolds number.

The conditions in the evaporator section of the heat pipe are found to be adequately described by similar solutions in both limits, and the characteristic of the flow in the transition from low to high Reynolds number is completely determined by the evaporator Reynolds number. The evaporator section is very weakly coupled to the condenser. The conditions in the condenser section are decidely more complex, and similar solutions are of value only for small Reynolds numbers for long tubes. The flow in the condenser depends upon the condenser Reynolds number, the evaporator Reynolds number and the condenser length to diameter ratio. Reverse flows occur for radial Reynolds numbers greater than 2 and occupy a substantial fraction of the condenser length.

Complete flow descriptions for symetrical and asymmetrical heat pipes are presented, and practical results for the calculation of pressure losses in low speed heat pipe vapor flows are given.

71128 MINIMUM MENISCUS RADIUS OF HEAT PIPE WICKING MATERIALS

C.L. Tien, K.H. Sun (Department of Mechanical Engineering, University of California, Berkeley) Int. Journal of Heat & Mass Transfer, Vol. 14, No. 11, pp.1853-1855, Avail: TAC

The article discusses and presents ways of calculating the minimum meniscus radius for various types of heat pipe wicking materials. One of the major features in the transport processes inside a heat pipe is the wick capillary pumping action for the return of condensate from the condenser to the evaporator, the limit of this capillary pumping plays a most significant role in the design of the heat pipe. This pumping pressure is a function of the minimum meniscus radius.

71129 ON THE SURFACE TENSION PUMPING OF LIQUIDS, OR, A POSSIBLE ROLE OF THE CANDLEWICK IN SPACE EXPLORATION

Lloyd Trefethen (Tufts University, Medford, Massachusetts) Prepared for General Electric Company, Missile and Space Vehicle Department, Unmanned Spacecraft Section (No. 61-SD-114), February 1962, 19 p., Avail: TAC

Self-pumping evaporating and condensing devices can be made by utilizing surface-tension forces at porous and at ribbed surfaces. How well they would perform is, apparently, not known.

It might be useful to study this method of pumping by surface tension to see whether it has applications in space, where gravity may not be effective and pumps are undesirable.

A proposed design of a cooling device for electronic packages is presented and discussed.

A number of questions to which answers might usefully be sought are listed.

D. DESIGN, DEVELOPMENT, AND FABRICATION

D. 1 General

71093 STATUS OF EMITTER HEAT PIPE DEVELOPMENT AT ISPRA
C.A. Busse, F. Geiger, D. Quataert (Presented at 1970 Thermionic Conversion Specialist Conference, 26-29 Oct. 70, Miami, Florida.) 6p. Avail: TAC

The development work on heat pipes for operation around 1600°C is concentrated on Li systems mainly for two reasons: 1) Li has a very high heat transfer capability at moderate vapor pressures, 2) a W/Li heat pipe has shown the minimum corrosion in early screening tests of 15 heat pipe combinations comprising Nb-1Zr, Ta, CVD-W as wall material and Bi, Pb, Tl, Li, Ba as working fluids. Successful corrosion inhibition has been demonstrated in 1000 hour tests with Nb-1Zr/Li at 1500°C and Ta/Li at 1600°C by sufficient deoxidation. A W-26Re/Li heat pipe has passed 6000 hours of operation at 1600°C with an average heating rate of 100 w/cm^2 without showing any signs of deterioration.

For temperatures around 2000°C Ag heat pipes are being studied. A first test of a W-26Re/Ag heat pipe showed after 1000 hours at 2000°C with an average heating rate of about 150 w/cm^2 moderate mass transport of an unusual pattern, which can not yet be explained.

71094 VARIABLE VAPOR VOLUME HEAT PIPES
R.W. Werner (California Univ., Livermore, Lawrence Radiation Lab.). August 9, 1966. (UCID - 15621) Avail: TAC

Design of a heat pipe which provides for a vapor volume which changes or adjusts as a function of input power is discussed. An illustrative example using steam is provided. The heat pipe as a temperature transducer is suggested.

71095 USER'S MANUAL FOR THE TRW GAS PIPE PROGRAM. A VAPOR-GAS FRONT ANALYSIS PROGRAM FOR HEAT PIPES CONTAINING NONCONDENSIBLE GAS.
D.K. Edwards, G.L. Fleischman, B.D. Marcus. TRW Systems Group, Redondo Beach, Calif. Apr. 1971, 88p. Ref. (Contract NAS2-5503) (NASA-CR-114306; TRW-13111-6072-R0-00). Avail: TAC

A digital computer program is described which is useful in the design and analysis of heat pipes which contain noncondensible gases; either for temperature control or to aid in start-up from the frozen state. The program includes the effects of axial conduction and mass diffusion on the performance of such heat pipes and permits the calculation of the wall temperature profile along a gas loaded heat pipe; the amount of gas loading necessary to obtain a desired evaporator temperature at a desired

71130 A FLEXIBLE HEAT PIPE
P.L. Miller, R.E. Roberts, ASHRAE Semiannual Meeting, Philadelphia, Pennsylvania, January 24-28, 1971, 5 p., Avail: TAC

Experiments have been conducted to determine the possibility of constructing and operating a flexible heat pipe which could have its configuration rearranged after assembly and yet maintain proper operation. The desired objective was accomplished with a water-filled heat pipe having a woven glass-fiber wick. The flexible portion of the unit was made of tygon and acted as an adiabatic transition section between the heat input and removal sections. The results obtained show that no significant change of the operating characteristics of the heat pipe could be traced to the bending of the device.

71131 PRINCIPLES AND INDUSTRIAL APPLICATION OF HEAT PIPES
P. Zimmerman, R. Pruschek (Inst. Kernenerg., Univ. Stuttgart, Stuttgart, Germany) Dechema (Deut. Ges. Chem. Apparatewesen) Monogr. 1970, 65 (1168-1192) 67-84, in German, Avail: TAC

The design of heat pipes is reviewed and the limits of their application are discussed. 22 refs.
heat load; the heat load versus the evaporator temperature for a fixed amount of gas in the pipe; the heat and mass transfer along the pipe, including the vapor-gas front region; the heat leak when the condenser is filled with gas; freezing occurance and rate in the condenser; and the information required to size the gas reservoir of gas controlled heat pipes. The program contains numerous reservoir options which allow it to be used for hot or cold reservoir passive control as well as heated reservoir active control heat pipes. Additional input options permit its use for parametric studies and off-design performance predictions as well as heat pipe design.

D. 2 Wicks

71096 RESEARCH STUDY ON INSTRUMENT UNIT THERMAL CONDITIONING PANEL FINAL REPORT
D.W. Graumann, C.E. Richard, J.D. Duncan, J.C. Gibson, C.S. Coe. etal (AiResearch Mf. Co., Los Angeles, Calif.) (Contract NAS8-11291) (NASA-CR-103190; Rept.-71-7133) May 1971, 239p. refs. Avail: TAC

A heat pipe panel 30 in. by 30 in. was designed, fabricated, and tested to the design requirements of the Saturn 5 vehicle. Investigations into wick materials, preservation of wick materials, and porous plate sublimation was performed in conjunction with a study of noncondensable hydrogen gas generator in 304 stainless steel heat pipes with water as the working fluid.

71132 DEVELOPMENT OF HIGH THERMAL POWER DENSITY AMMONIA HEAT PIPES

Philip E. Eggers, Aleck W. Serkiz, Richard J. Burian, ASME Winter Annual Meeting, Washington, D.C., November 28-December 2, 1971, ASME No. 71-WA/HT-20, Avail: TAC

A totally metallurgically bonded heat pipe concept has been developed utilizing an advanced porous-grooved wick. This wick design features the combined advantages of low viscous losses due to reflux of working fluid which is characteristic of grooved wick designs, and the high capillary-pumping capability attributable to porous wick structures. As a result, this composite wick design provides significantly higher heat-transport capacities than otherwise possible with the individual wick concepts, viz, grooved or porous wicks. In addition, the metallurgically bonded heat pipe provides a high radial thermal conductance in the wick/container composite. The present paper describes the heat pipe design as well as the experimental results of 0.48-cm diameter by 18-cm long ammonia heat pipe. In these experiments, an ammonia heat pipe operated at radial thermal fluxes of up to 18 watts/in.^{2} with less than a 9 K temperature difference between the evaporator and condenser.

71133 DESIGN AND DEVELOPMENT OF A PROTOTYPE STATIC CRYOGENIC HEAT TRANSFER SYSTEM

Dynatherm Corporation, Cockeysville, Maryland, Final Report, August 1971, 88 p. refs. (Contract NAS5-21191 (NASA-CR-121939, DTM-50-5D) Avail: TAC

An analysis was conducted which verified the high performance capability of a nonwetting cryogenic capillary-pumped loop. As a result, an investigation was undertaken to determine the feasibility of obtaining a nonwetting cryogenic liquid/solid combination. Results of a literature search indicated that this was feasible for cryogenic liquids provided that low energy solid surfaces are used. Contact angle measurements of liquid nitrogen, oxygen, and Freon 13 on various low energy surfaces were made. The results of these measurements showed that all of the test samples were wet by the different cryogenic liquids; the highest contact angle measured was 30 degrees. However, for a high-performance static cryogenic heat transfer system the development of a heat pipe which utilized a wetting arterial wick was pursued. An experimental model whose artery design was optimized to facilitate start-up was fabricated and tested. Nitrogen was used as the working fluid. The experimental model has a heat transport capability greater than 1500 watt-cm which is well in excess of projected requirements for spacecraft applications employing cryogenic heat pipes.

D.3 Materials

71066 MATERIAL PROBLEMS AT HIGH TEMPERATURE HEAT PIPES (WERKSTOFFPROBLEME BEI HOCHTEMPERATUR-WARMEROHREN)
Claus A. Busse , Forschung im Ingenieurwesen, vol. 37, no. 2, 1971, p. 38-43, 16 refs. In German, Avail:TAC

Mechanisms involved in the corrosion of the heat pipes are discussed. One mechanism connected with the solubility of the wall material in the heat carrier is responsible for mass transfer from the cooling zone into the heating zone. Another mechanism related to the accumulation of impurities in the heating zone leads to corrosion attack at the wall of that area. Approaches for avoiding heat zone corrosion are described. An operational heat pipe life of 10,000 hr. in a temperature range from 1500 to 2000 deg is thought possible.

71097 POROUS LININGS FOR HEAT PIPES
Gregor Gammel, Peter Batzies (Brown, Boveri and Cie, A-G) Ger. Offen. 1,950,439 (Cl. C23C), 15 Apr. 1971, Appl. 07 Oct. 1969, 7pp. Avail: TAC

Porous linings with varying capillary structure for good heat transfer were obtained in heat pipes by vapor-plating volatile lining material under redn. or decompn., and sealing the porous lining by a final dense layer.

71098 CORROSION MECHANISM IN TANTALUM-LITHIUM HIGH-TEMPERATURE HEAT PIPES BY ION ANALYSIS
Didie Quataert (Ispra, Italy), Forsch. Ingenieurw. 1971, 37(2), 37-8. Avail: TAC

Samples of the stabilized-grain-size, Ta heat pipe material, annealed in ultrahigh vacuum at 1600^{o} showed that complete recrystn. took place in $<$15 min, that grain growth occurred, and YO_2pptd. at the grain boundaries. A heat pipe of Ta with Li as the heat carrier was operated at 1600^{o} for 2100 hr. In the cooling zone, a YO_2 depleted zone was noted at the inner side of the heat pipe. In the heating zone, the pipe had failed by perforation. A black deposit around the hole was examd. by metallog. and an ion analyser. An intergranular corrosion phase and the black deposit gave emission of O^-,Y^+,Li^+, and

Ta^+ ions. Platelets inside the grains in contact with the corrosion phase gave emission of Ta^+, O^-, and TaO^+, but no Li or Y. The dissvoled Ta of the corroded zone was redeposited in the capillaries of the heating zone ~0.5 mm above the corrosion zone.

71134 FABRICATION AND TESTING OF TUNGSTEN HEAT PIPES FOR HEAT PIPE COOLED REACTORS

Robert J. Bacigalupi, NASA, Lewis Research Center, Cleveland, Ohio, 1971, 7 p., refs. presented at the Thermionic Conversion Specialists Conference, San Diego, California, October 4-6, 1971 (NASA-TM-X-67941; E-6620) Avail: TAC

The heat pipes described here were designed and fabricated with the following criteria in mind: operation at 1850 K in contact with nuclear fuel; axial heat flux greater than 7 kW/sq cm; and a configuration allowing direct coupling to a cross flow heat pipe exchanger. Chemically vapor deposited tungsten was used as the outer shell and lithium as the working fluid. Both annular and channeled wicks were investigated along with methods of wick fabrication using tungsten and tungsten rhenium. Calorimetric heat throughput measurements at various operating temperatures are presented.

71135 HEAT PIPE HAVING A ZERO CONTACT ANGLE WITH AN ALKALI METAL WORKING FLUID

Harold F. Webster (General Electric Company) U.S. 3,598,177 (Cl. 165/1; F 28d), August 10, 1971, Appl. October 29, 1968, 6 p., Avail: TAC

A heat pipe capable of operation at $>900^{\circ}$ is described. The system is characterized by an alkali metal working fluid contained in a conduit having a crystal-face orientation only in selected planes to maximize the wetting between the sidewall and the working fluid. The conduit is provided with circumferentially-disposed inwardly-extending teeth overlayed with a thin wire mesh screen to define capillary passages for liquid transport. The surface of the passages contains the metal only in planes having work functions below a fixed value, e.g., 4.8 eV, for a Na working fluid with the desired orientation of the capillary passage surface being formed by a H reduction of a metal fluoride.

The zero contact angle between the working fluid and the conduit permits the initiation of operation of the heat pipe without prior warm-up, and eliminates localized hot spots destructive to the sidewall structure. Thus, a heat pipe having a 1/2-in. diameter, 40-mil thick Nb conduit can withstand an internal pressure of 6400 psi

($\sim$400 atm) of Cs, permitting Cs to be raised to 1100^{o} without exceeding the tensile strength of the conduit.

E. TESTING AND OPERATION

71099 HEAT - TRANSFER APPARATUS (HEAT PIPE)
L.L. Vasil'Ev, S.V. Konev (Inst. Teplo-Massoobmena, Minsk, USSR). Inzh-Fiz. Zh. 1971, 20 (3), 550-66 (Russ).

The authors review heat pipes classified in operating regions 1200-2000, 400-1200, and <400°K. The operation of heat pipes was analyzed math. An exptl. low-temp. (<400°K) pipe was constructed and tested with EtOH and H_2O. From test data for NH_3, H_2O, MeOH, EtOH, Me_2CO, H, He, and Freon-12, the most effective heat-transfer agents in the low-temp. heat pipe are NH_3 and H_2O. In the region of liq.-He temps., He II appears to be promising for use at <2°K.

71136 ISOTOPE KILOWATT PROGRAM QUARTERLY PROGRESS REPORT FOR PERIOD ENDING MARCH 31, 1971
Oak Ridge National Lab, Tennessee, May 1971, (NRNL-TM 3394), Contract W-7405-eng-26 26 p., Avail: TAC

The organic capsule test continued during the quarter without an interruption and has accumulated 2180 hours as of the end of March. The detail design of the 1/4 scale organic fluid evaluation loop was completed. The heat block forging has been procured and the specifications for the pumps are out for bids. A glass loop has been built to mock-up the 1/4 scale organic fluid test loop. Results of operation experience analyses indicate that good startup, fluid flow stability, and control precision characterize the loop. Both startup and operating tests at 1000 to 1500°F were made on the heat pipe. No performance data was obtained because of the failure of a differential thermopile. A new thermopile has been fabricated and calibrated. The heat pipe for the thermoelectric module was completed. Fabrication of the thermoelectric module was completed and testing was initiated. The test was stopped 9 hours after startup because of the failure of two nickel wire leads to the heaters. Subsequent examination of the loop and chemical analysis of sections of the wire showed that the lead broke because of embrittlement by sulfur and possibly cadmium contamination. The test was shut down pending analysis of scrapings and fillings taken from various parts of the system to determine the extent to which other parts might have been adversely affected. The assembly of the test section for the next series of tests on the aluminum wire screen insulation was completed. Aluminum alloy 1100 has been selected for the fusible insulation for the organic and low-temperature (PbTe) thermoelectric units and an order placed for the material. Tests were started to determine the effective thermal conductivity of the aluminum screen insulation as a function of pressure. The design of the full-scale heat block-shield has been completed and the drawings have been sent out for bids.

71137 PERFORMANCE LIMITS, TECHNOLOGY, AND APPLICATION OF LOW-TEMPERATURE HEAT PIPES

Manfred Groll, Ortwin Brost, Helmut Kreeb, Klaus P. Schubert, Peter Zimmerman (Stuttgart, Germany) Forsch. Ingenieurw., 1971, 37 (2), 33-7 in German, Avail: TAC

The importance of degassing heat pipes by contact with other gases or in vacuum, or by ultrasonic treatment, is stressed. A tabulation shows the various fluids for use in the -200° to 550° temperature range, with the various pipe metals for which they are suitable, the individual temperature range, and the axial radial heat flow ds. The results of performance tests on 6 fluids over a period of 700-2100 hours are given in terms of drop in axial temperature in the cooling zone. Several examples of the application of low temperature heat pipes are given.

71138 THE FEASIBILITY OF ELECTROHYDRODYNAMIC HEAT PIPES

T.B. Jones (Department of Electrical Engineering, Colorado State University, Fort Collins) Research Report No. 1, prepared for AMES Research Center, NASA, Moffett Field, California, October 1971, 56 p., Avail: TAC

This first research report presents the results obtained to date in a study undertaken to explore the feasibility of the electrohydrodynamic heat pipe concept. The work has been divided into three research tasks involving theory of operation, design criteria, and evaluation of optional design features.

71139 PRELIMINARY TEST RESULTS OF HEAT TRANSFER/THERMAL STORAGE TUBE DESIGN UNDER SIMULATED ORBITAL CONDITIONS

David Niamkoong, NASA, Lewis Research Center, Cleveland, Ohio, August 1971, 52 p., refs. (NASA-TM-X-67904), Avail: TAC

Heat-receiver tubes were tested as part of an investigation of a heat receiver for a solar Brayton-cycle power system. The tubes were designed to store excess solar energy during the orbital sunlit period and then to transfer the heat energy to the flowing gas during the orbital shade period. In this way constant thermal input to the Brayton system would be maintained over the entire orbit. The tubes utilized the heat of fusion of lithium fluoride as the heat-storage medium and were designed to accommodate the 23 percent volume change of LiF during phase changes. The columbium 1% zirconium tubes operated under a simulated oribital condition for 2002 hours and 1251 sun shade cycles before going into a scheduled shutdown. Although there were no gross distortions of the convoluted LiF storage tubes, local distortions were detected. During operation, the gas discharge temperature varied from 30 degrees below nominal at the end of the shade period to 50 degrees above at the end of sunlit period. Surface temperatures along the tube ranged from 1410 F to 1670 F.

71140 PERFORMANCE CHARACTERISTICS OF ROTATING NON-CAPILLARY HEAT PIPES

Walter Hughes Newton, Jr. (Naval Post Graduate School, Monterey, California) Masters Thesis, June 1971, 61 p. Avail: TAC

A Nusselt-type analysis was performed for laminar film condensation on the inside of a rotating truncated cone with small half cone angles. This analysis included the interfacial shear between the vapor and condensate, the vapor pressure drop, the thermal resistance in the condenser wall, and the condenser outside cooling mechanism. An approximation of the analytical model made it possible to find a numerical solution for small half cone angles greater than zero. A non-capillary rotating heat pipe containing an evaporator, condenser, and distilled water as the working fluid was tested. It was rotated at 702 and 1404 RPM, and the heat transfer rates of the heat pipe were determined experimentally for different saturation temperatures corresponding to electrical power inputs ranging from 1 kW to 9 kW. The experimental results showed that the non-capillary rotating heat pipe was an effective heat transfer device. The approximate numerical solution conservatively predicted the heat transfer rate with a deviation of 18% at 702 RPM and 5% at 1404 RPM.

71141 ISOTOPE KILOWATT PROGRAM QUARTERLY PROGRESS REPORT FOR PERIOD ENDING JUNE 30, 1971

A.P. Fraas, G. Samuels, (Oak Ridge National Lab, Tennessee) August 1971, (ORNL-TM-3491) Contract W-7405-eng-26, 20 p., Avail: TAC

The organic capsule test continued during the quarter without interruption and has accumulated 4370 hours of operation as of the end of June. The design review of the one-quarter scale organic fluid decomposition test loop was completed and the Quality Assurance Program plan was revised. The instrumentation application drawing was approved and drawings showing the electrical and instrumentation control systems were completed. Tests with the glass mockup of the quarter-scale organic test loop demonstrate that the boiler flow stability is excellent even with one boiler tube operating at zero power and the other two at full power. Similarly, tests covering a wide range of other highly unbalanced operating conditions have disclosed no undesirable characteristics. Procurement of hardware for the quarter-scale organic fluid evaluation test loop is underway. The heat block-shield unit has been completed, inspected, and loaded with $SrTiO_3$. Radiation dose rates as a function of position are being determined. Fabrication of the piping has been delayed but will begin in July as soon as the full complement of final approvals have been obtained. Heat pipe tests at ORNL under a wide range of power and attitude conditions indicate peculiarties in the performance characteristics. Several hypotheses that have been advanced to explain all of these peculiarities have been investigated. Nondestructive diagnostic tests to determine the reason for its unusual behavior have included radiographs (which revealed a gas bubble in the lower end of the pipe) and eddy current tests. The results indicate that the anomalous behavior of the heat pipe has been caused by one or more bubbles of a non-condensible gas other than hydrogen (probably argon) trapped between the wick and the outer tube. The potassium will be removed and, after a thorough bake-out, the pipe will be reloaded. The thermoelectric module test was restarted after replacing the heaters, but the hermetic seal at the base of the thermoelectric region failed. Tests of the original wire screen thermal insulation indicated that paint on the wire might increase its emissivity, thus increasing its effective thermal conductivity. New wire screen free of paint and with a sharper melting point was procured and tested, but showed no improvement. Thin (.002 in.) sheets of foil of alloy 5052 will be used in an effort to reduce the radiation loss in the next test. All of the components for the heat block-shield test are in various stages of procurement except for the screen insulation and vacuum tank. Delivery of the major item, the heat block-shield assembly, is scheduled for September 1, 1971. Fabrication of the screen and tank will not be started until the screen thermal conductivity values are obtained with the foil.

71142 TEST OF 50-KW HEAT PIPE RADIATOR
G.M. Kikin, M.L. Peelgren, ASME Winter Annual Meeting, Washington, D.C., November 28-December 2, 1971, ASME No. 71-WA/HT-16, Avail: TAC

A heat pipe radiator consisting of 100 sodium filled, 1.91 cm (3/4 in) O.D., stainless steel heat pipes has been tested at temperatures up to 760 C (1400 F). These tests at the Jet Propulsion Laboratory were conducted on the heat pipe radiator which was designed and fabricated by RCA for the Air Force Aero Propulsion Laboratory at Wright Patterson AFB. This radiator was initially designed to have a heat pipe temperature of 740 C with a central coolant channel temperature of 771 C. The as-fabricated radiator heat pipe temperatures varied from 605 C to 700 C when the central coolant channel average temperature was 740 C. The heat pipes operated at 25 C to 110 C lower than expected temperatures resulting in a 43 kW heat rejection capability versus the 50 kW design goal and the 65 kW ultimate capability of the radiator. The 43 kW heat rejection yields a mass/heat rejection ratio of 0.182 kg/kWt which is good for this early state-of-the-art heat pipe radiator. An end-of-mission life specific weight of 0.154 kg/kW is apparently achievable with improvements in radiator fabrication and brazing techniques.

71143 SOME EXPERIMENTS ON SCREEN WICK DRY-OUT LIMITS
K.R. Chun, ASME Winter Annual Meeting, Washington, D.C., November 28-December 2, 1971, ASME No. 71-WA/HT-6, Avail: TAC

Dry-out limits of screen wicks vertically pumping against gravity above an acetone pool were determined in evaporation experiments. As the pumping height shortened, the increase in heat input at dry-out became less than that expected from a fully saturated wick layer. The receding of the evaporating boundary into a sublayer of the wick was postulated, based on the fact that the measured thermal resistance across the wick layer decreased as heat input increased. Such a recess seems to terminate at two layers above the heated wall. A new wicking model taking into account the receding of evaporation boundary could predict the experimental dry-out heat inputs within ten percent.

71144 EXPERIMENTAL STUDY OF A NITROGEN HEAT PIPE
B.F. Armaly, Jay Dudheker, ASME Winter Annual Meeting, Washington, D.C., November 28-December 2, 1971, ASME

No. 71-WA/HT-28, Avail: TAC

An experimental investigation is described concerning the operating characteristics of a nitrogen heat pipe, 33.25 inches long, with an adiabatic section of 13.25 and a diameter of 0.75 inches. The axial temperature distribution and the vapor pressure were measured for various power loads at different angles of inclination. The effective thermal conductivity, based on a section 17.25 inches long, decreased with increasing loads and with decreasing angle of inclination (evaporator below condenser). For the horizontal operating condition, the effective thermal conductivity varied between 10 and 5 times that of copper at the same average temperature, while the load varied between 10 and 110 watts. The results indicate that the thermal radial resistance at the evaporator section is the major factor limiting the maximum power load of such a heat pipe.

71145 ARTERIAL AND GROOVED CRYOGENIC HEAT PIPES
Patrick Brennan, Donald Trimmer, Allan Sherman, Thomas Cygnarowicz, ASME Winter Annual Meeting, Washington, D.C., November 28-December 2, 1971, ASME No. 71-WA/HT-42, Avail: TAC

Tests were conducted on two cryogenic heat pipes using nitrogen as the working fluid. Both pipes are 1.27 cm in diameter. The first pipe is 141 cm long and uses longitudinal grooves in the aluminum wall as the wick structure. At an evaporator elavation of 0.19 cm, a heat transfer rate of 12.6 watts and a heat transport capability of 1650 watt-cm are obtained with a maximum ΔT along the length of the pipe of 9^{o}C. The static elevation head is .72cm. The second pipe is 91 cm long and has an arterial wick adjacent to the wall. In addition, circumferential screw threads are machined along the entire length of the inside pipe wall. At an evaporator elevation of 0.254 cm, a heat transfer rate of 25 watts and a heat transport capability of 1850 watt-cm are obtained with a maximum ΔT along the length of the pipe of 18^{o}C. The static elevation head is 3.75 cm.

Both heat pipes primed with no difficulty in the horizontal position. Start-up after burn-out was obtained repeatedly. However, more testing is required to determine whether the artery pipe is as reliable as the grooved pipe with respect to priming.

Once primed, the artery heat pipe is much less sensitive to elevation than the grooved design, and consequently, offers a significant advantage with respect to ground testing. Heat transfer characteristics of the two pipes were comparable, with both pipes achieving the initial goal of 1000 watt-cm of heat transport capability.

71146 TRANSIENT THERMAL IMPENDANCE OF A WATER HEAT PIPE
S.W. Kessler, Jr. ASME Winter Annual Meeting, Washington, D.C., November 28-December 2, 1971, ASME No. 71-WA/HT-9, Avail: TAC

A silicon rectifying junction was used as a heat source to study the transient thermal impedance of water heat pipes. The temperature of the evaporator, the vapor space, and the condenser of the heat pipes were monitored. The operation of the heat pipes were observed during the time period of 8.3 ms to 1,000s. After 200s the heat pipes were operating in a steady-state mode. The heat pipes were successfully started with peak heat fluxes of 105 W/cm^2 with the working fluid frozen as well as in a liquid state. An analysis was made of both start-up conditions. The heat pipes were also pulsed to a power density of 2,500 W/cm^2.

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EXPERIMENTAL STUDY OF A NITROGEN HEAT PIPE
ASME WINTER ANNUAL MEETING WASHINGTON, D.C., NOV 28-DEC2, 1971. ASME NO. 71-WA/HT-28. AVAIL-TAC

00020 BACICALUPI R J 71134 36
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00070	BACK-CONTROLLED VA/ TRANSIENT	PERFORMANCE OF ELECTRICAL FEED	71089	23
00280	QUARTERLY PROGRESS REPORT FOR	PERIOD ENDING JUNE 30, 1971.# /	71141	40
00970	QUARTERLY PROGRESS REPORT FOR	PERIOD ENDING MARCH 31, 1971.#	71136	38
		'PIPE ' NOT INDEXED		
00650	UID FLOW IN THE DUCTOF A HEAT	PIPE.# /HE HYDRODYNAMICS OF FL	71092	29
00310	INE CYCLE VAPOR CHAMBER (HEAT	PIPE) RADIATOR STUDY# /UM RANK	71110	16
00830	HEAT-TRANSFER APPARATUS (HEAT	PIPE)#	71099	38
		'PIPES ' NOT INDEXED		
00920	DYNAMIC BEHAVIOR OF HEAT	PIPES.#	71117	25

00520	MIKIELEWICZ J	71050	1
00560	MILLER P L	71130	33
00770	MOSKOWITZ S	71104	7
00240	MYNATT F R	71109	15
00570	NAMKOONG D	71139	39
00580	NEU H	71060	17
00260	NEU H	71058	17
00270	NEU H	71059	17
00590	NEWTON W H	71140	40
00600	NIEDERAUER G	71111	17
00610	OHERN E A	71113	23
00620	PARKER M B	71061	18
00630	PAULUIS G	71120	26
00640	PAWLOWSKI P H	71118	25
00460	PEELGREN M L	71142	42
00650	POTAPOV I F	71092	29
00930	PRUSCHEK R	71131	33
00660	PRUSCHEK R	71077	10
00670	QUAST A	71125	28
00680	QUATAERT D	71098	35
00120	QUATAERT D	71093	32
00610	RAKOWSKE J E	71113	23
00330	RICHARD C E	71096	33
00560	ROBERTS R E	71130	33
00800	ROHANI A R	71115	24
00660	ROHRBORN B	71077	10
00700	ROUKLOVE P	71107	11
00690	ROUKLOVE P	71106	11
00280	SAMUELS G	71141	40
00710	SCHLITT K R	71074	5
00350	SCHUBERT K P	71137	39
00720	SEBAN R A	71123	27
00730	SEMERIA R	71070	2
00230	SERKIZ A W	71132	34
00090	SHERMAN A	71145	43
00770	SIEVERS A	71104	7
00750	SILVERSTEIN C C	71122	27
00740	SILVERSTEIN C C	71121	26
00030	SMITH H J	71127	30
00760	SOCKOL P M	71067	28
00910	SPEIDEL V	71108	12
00770	STAPPENBECK A	71104	7
00810	SUN K H	71128	31
00290	SUTHERLAND	71112	19
00290	SWICKARD E O	71112	19
00780	TAWIL M N	71057	12
00790	TAWIL M N	71083	15
00810	TIEN C L	71128	31
00800	TIEN C L	71115	24
00820	TREFETHEN L	71129	31
00090	TRIMMER D	71145	43
00700	TRUSCELLO V	71107	11
00650	TSAGI Z U	71092	29
00660	UNGER H	71077	10

00009 ZUBER N ET AL
VAPORIZING HEAT TRANSFER DEVICE
U.S. PATENT 3392781
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00010 KUN L C ET AL
SURFACE FOR BOILING LIQUIDS
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00011 FINKIN E
INTERNALLY COOLED MOTION CONTROL SYSTEM - HEAT PIPE BRAKES
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00012 GRITTON E C PINKEL B
GASEOUS-FUELED NUCLEAR REACTORS FOR ELECTRICAL POWER PRODUCTION
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00013 NUE H FIEBELMANN P
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00014 FIEBELMANN P NEU H
BUZZI U
NUCLEAR POWER PLANT FOR A SPACE STATION
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JAN 27, 1971

00015 FIEBELMANN P NEU H
BUZZI U
NUCLEAR POWER PLANT FOR A SPACE STATION
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00016 BAER S C
HEAT PIPE CONDENSATE RETURN
U.S. PATENT 3561525
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00017 BASIULIS A
HEAT PIPE HAVING IMPROVED DIELECTRIC STRENGTH

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00018 HARBAUGH W E
HEAT PIPE
U.S. PATENT 3568762
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00019 EDWARDS R N
UNDERWATER HEAT EXCHANGE SYSTEM
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00020 TRENT D S
HEAT PIPE
U.S. PATENT 3576210
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00021 BASIULIS A
HEAT PIPE HAVING A SUBSTANTIALLY UNIDIRECTIONAL THERMAL PATH
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00022 MILTON R M
HEAT EXCHANGE SYSTEM WITH POROUS BOILING LAYER
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00023 BECKER R A
THERMIONIC CONVERTER CELLS FOR NUCLEAR REACTOR
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00024 LEFFERT C B
DISC BRAKE COOLING
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00025 LEFFERT C B HAFSTAN L R
BRAKE HEAT PIPE COOLING
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00026 MCHUGH K L

ORGANIC FLUIDS FOR HEAT PIPES
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00027 WEBSTER H F
CONDUIT HAVING A ZERO CONTACT ANGLE WITH AN ALKALI WORKING FLUID AND METHOD OF FORMING
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00028 STUAB F W
HEAT PIPE
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00029 MOORE R D
HEAT TRANSFER SURFACE STRUCTURE
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00030 BUSSE C A
FUEL ELEMENTS FOR USE IN THERMIONIC NUCLEAR REACTORS
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00031 KRAFT G POTZSCHKE M
BUSSE C A GEIGER F
HEAT TRANSFER TUBE ASSEMBLY
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00032 SASSIN W
PIPE SYSTEM FOR LOW-TEMPERATURE FLUIDS
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00033 LEVEDAHL W J FRANK S
VALVED HEAT PIPE
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00034 FELDMAN K T KUSIANOVICH J D
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00035 KESSLER S W HESS J L
FLEXIBLE HEAT PIPE
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00036 FREGGENS R A HARRBAUGH W E
ELECTRICAL CONNECTOR ASSEMBLY HAVING COOLING CAPABILITY
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00037 COLEMAN J B
HEAT PIPE WITH VARIABLE EVAPORATOR
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00038 LAZARIDIS L J
GLASS FURNACE WITH HEAT PIPE MELTING
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00039 LEFFERT C B
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00040 HALL W B BLOCK F G
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00041 FELDMAN K T
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00042 COLEMAN J B WELSCH J P
DUAL TUBE HEAT PIPE AND MEANS FOR CONTROL THEREOF
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00044 FRANK S
VEHICLE-HEATING SYSTEM EMPLOYING A CRITICAL POINT HEAT PIPE
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00045 SOMERVILLE R H BAKKER L P
CONTINOUS HEAT PIPE AND ARTERY CONNECTOR THERE FOR
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00046 LEFFERT C B
CONTROL SYSTEM FOR HEAT PIPES
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NOV. 23, 1971

00047 REIMERS E
CAPACITOR ENERGY STORAGE IMPROVEMENT BY MEANS OF HEAT PIPE
U.S. PATENT 3622846
NOV. 23, 1971

		'A ' NOT INDEXED
00027	HAVING A ZERO CONTACT ANGLE WITH AN	ALKALI WORKING FLUID AND METHOD OF F
		'AN ' NOT INDEXED
		'AND ' NOT INDEXED
00027	ND M/ CONDUIT HAVING A ZERO CONTACT	ANGLE WITH AN ALKALI WORKING FLUID A
00045	CONTINOUS HEAT PIPE AND	ARTERY CONNECTOR THERE FOR#
00036	ELECTRICAL CONNECTOR	ASSEMBLY HAVING COOLING CAPABILITY#
00031	HEAT TRANSFER TUBE	ASSEMBLY#
00022	HEAT EXCHANGE SYSTEM WITH POROUS	BOILING LAYER#
00010	SURFACE FOR	BOILING LIQUIDS#
00024	DISC	BRAKE COOLING#
00025		BRAKE HEAT PIPE COOLING#
00039	DRUM	BRAKE HEAT PIPE COOLING#
00011	D MOTION CONTROL SYSTEM - HEAT PIPE	BRAKES# INTERNALLY COOLE
		'BY ' NOT INDEXED
00036	L CONNECTOR ASSEMBLY HAVING COOLING	CAPABILITY# ELECTRICA
00047	BY MEANS OF HEAT PIPE'	CAPACITOR ENERGY STORAGE IMPROVEMENT
00023	THERMIONIC CONVERTER	CELLS FOR NUCLEAR REACTOR#
00016	HEAT PIPE	CONDENSATE RETURN#
00027	WITH AN ALKALI WORKING FLUID AND M/	CONDUIT HAVING A ZERO CONTACT ANGLE
00036	PABILITY# ELECTRICAL	CONNECTOR ASSEMBLY HAVING COOLING CA
00045	CONTINOUS HEAT PIPE AND ARTERY	CONNECTOR THERE FOR#
00040	E#	CONSTANT TEMPERATURE OUTPUT HEAT PIP
00027	FLUID AND M/ CONDUIT HAVING A ZERO	CONTACT ANGLE WITH AN ALKALI WORKING
00045	CTOR THERE FOR#	CONTINOUS HEAT PIPE AND ARTERY CONNE
00011	INTERNALLY COOLED MOTION	CONTROL SYSTEM - HEAT PIPE BRAKES#
00046		CONTROL SYSTEM FOR HEAT PIPES#
00042	DUAL TUBE HEAT PIPE AND MEANS FOR	CONTROL THEREOF#
00023	THERMIONIC	CONVERTER CELLS FOR NUCLEAR REACTOR#
00011	PIPE BRAKES# INTERNALLY	COOLED MOTION CONTROL SYSTEM - HEAT
00036	LECTRICAL CONNECTOR ASSEMBLY HAVING	COOLING CAPABILITY# E
00039	DRUM BRAKE HEAT PIPE	COOLING#
00024	DISC BRAKE	COOLING#
00025	BRAKE HEAT PIPE	COOLING#
00044	VEHICLE-HEATING SYSTEM EMPLOYING A	CRITICAL POINT HEAT PIPE#
00043	HEAT TRANSFER	DEVICE#
C0009	VAPORIZING HEAT TRANSFER	DEVICE#
00017	HEAT PIPE HAVING IMPROVED	DIELECTRIC STRENGTH#
00024		DISC BRAKE COOLING#
00039		DRUM BRAKE HEAT PIPE COOLING#
00042	NTROL THEREOF#	DUAL TUBE HEAT PIPE AND MEANS FOR CO
00036	COOLING CAPABILITY#	ELECTRICAL CONNECTOR ASSEMBLY HAVING
00012	GASEOUS-FUELED NUCLEAR REACTORS FOR	ELECTRICAL POWER PRODUCTION#
00030	AR REACTORS# FUEL	ELEMENTS FOR USE IN THERMIONIC NUCLE
00044	# VEHICLE-HEATING SYSTEM	EMPLOYING A CRITICAL POINT HEAT PIPE
00047	OF HEAT PIPE CAPACITOR	ENERGY STORAGE IMPROVEMENT BY MEANS
00037	HEAT PIPE WITH VARIABLE	EVAPORATOR#
00022	LAYER# HEAT	EXCHANGE SYSTEM WITH POROUS BOILING
00019	UNDERWATER HEAT	EXCHANGE SYSTEM#
00041	S#	FLAT PLATE HEAT WITH STRUCTURAL WICK
00035		FLEXIBLE HEAT PIPE#
00027	ONTACT ANGLE WITH AN ALKALI WORKING	FLUID AND METHOD OF FORMING# /ZERO C
00026	ORGANIC	FLUIDS FOR HEAT PIPES#
00032	PIPE SYSTEM FOR LOW-TEMPERATURE	FLUIDS#

00015	ICN#	NUCLEAR POWER PLANT FOR A SPACE STAT
00013		NUCLEAR REACTOR WITH HEAT PIPES#
00023	THERMICNIC CCNVERTER CELLS FOR	NUCLEAR REACTOR#
00012	R PRODUCTION# GASEOUS-FUELED	NUCLEAR REACTORS FOR ELECTRICAL POWE
00030	FUEL ELEMENTS FOR USE IN THERMIONIC	NUCLEAR REACTORS#
		'OF ' NOT INDEXED
00026		ORGANIC FLUIDS FOR HEAT PIPES#
00040	CONSTANT TEMPERATURE	OUTPUT HEAT PIPE#
00021	UBSTANTIALLY UNIDIRECTIONAL THERMAL	PATH# HEAT PIPE HAVING A S
00047	TORAGE IMPROVEMENT BY MEANS OF HEAT	PIPE CAPACITOR ENERGY S
00045	CONTINOUS HEAT	PIPE AND ARTERY CONNECTOR THERE FOR#
00042	DUAL TUBE HEAT	PIPE AND MEANS FOR CONTROL THEREOF#
00011	COOLED MOTION CONTROL SYSTEM - HEAT	PIPE BRAKES# INTERNALLY
00016	HEAT	PIPE CONDENSATE RETURN#
00039	DRUM BRAKE HEAT	PIPE COOLING#
00025	BRAKE HEAT	PIPE COOLING#
00021	TIONAL THERMAL PATH# HEAT	PIPE HAVING A SUBSTANTIALLY UNIDIREC
00017	NGTH# HEAT	PIPE HAVING IMPROVED DIELECTRIC STRE
00038	GLASS FURNACE WITH HEAT	PIPE MELTING#
00032	DS#	PIPE SYSTEM FOR LOW-TEMPERATURE FLUI
00037	HEAT	PIPE WITH VARIABLE EVAPORATOR#
00035	FLEXIBLE HEAT	PIPE#
00033	VALVED HEAT	PIPE#
00040	CONSTANT TEMPERATURE OUTPUT HEAT	PIPE#
00018	HEAT	PIPE#
00020	HEAT	PIPE#
00028	HEAT	PIPE#
00044	TEM EMPLOYING A CRITICAL POINT HEAT	PIPE# VEHICLE-HEATING SYS
00046	CONTROL SYSTEM FOR HEAT	PIPES#
00034	HEAT	PIPES#
00026	ORGANIC FLUIDS FOR HEAT	PIPES#
00013	NUCLEAR REACTOR WITH HEAT	PIPES#
00015	NUCLEAR POWER	PLANT FOR A SPACE STATION#
00014	NUCLEAR POWER	PLANT FOR A SPACE STATION#
00041	FLAT	PLATE HEAT WITH STRUCTURAL WICKS#
00044	HEATING SYSTEM EMPLOYING A CRITICAL	POINT HEAT PIPE# VEHICLE-
00022	HEAT EXCHANGE SYSTEM WITH	POROUS BOILING LAYER#
00014	NUCLEAR	POWER PLANT FOR A SPACE STATION#
00015	NUCLEAR	POWER PLANT FOR A SPACE STATION#
00012	LED NUCLEAR REACTORS FOR ELECTRICAL	POWER PRODUCTION# GASEOUS-FUE
00012	CLEAR REACTORS FOR ELECTRICAL POWER	PRODUCTION# GASEOUS-FUELED NU
00013	NUCLEAR	REACTOR WITH HEAT PIPES#
00023	RMIONIC CONVERTER CELLS FOR NUCLEAR	REACTOR# THE
00012	TION# GASEOUS-FUELED NUCLEAR	REACTORS FOR ELECTRICAL POWER PRODUC
00030	MENTS FOR USE IN THERMIONIC NUCLEAR	REACTORS# FUEL ELE
00016	HEAT PIPE CONDENSATE	RETURN#
00015	NUCLEAR POWER PLANT FOR A	SPACE STATION#
00014	NUCLEAR POWER PLANT FOR A	SPACE STATION#
00014	NUCLEAR POWER PLANT FOR A SPACE	STATION#
00015	NUCLEAR POWER PLANT FOR A SPACE	STATION#
00047	PIPE# CAPACITOR ENERGY	STORAGE IMPROVEMENT BY MEANS OF HEAT
00017	EAT PIPE HAVING IMPROVED DIELECTRIC	STRENGTH# H
00041	FLAT PLATE HEAT WITH	STRUCTURAL WICKS#
00029	HEAT TRANSFER SURFACE	STRUCTURE#

00021	FATH# HEAT PIPE HAVING A	SUBSTANTIALLY UNIDIRECTIONAL THERMAL
00010		SURFACE FOR BOILING LIQUIDS#
00029	HEAT TRANSFER	SURFACE STRUCTURE#
00011	INTERNALLY COOLED MOTION CONTROL	SYSTEM - HEAT PIPE BRAKES#
00044	AT PIPE# VEHICLE-HEATING	SYSTEM EMPLOYING A CRITICAL POINT HE
00046	CONTROL	SYSTEM FOR HEAT PIPES#
00032	PIPE	SYSTEM FOR LOW-TEMPERATURE FLUIDS#
00022	HEAT EXCHANGE	SYSTEM WITH POROUS BOILING LAYER#
00019	UNDERWATER HEAT EXCHANGE	SYSTEM#
00032	PIPE SYSTEM FOR LOW-	TEMPERATURE FLUIDS#
00040	CONSTANT	TEMPERATURE OUTPUT HEAT PIPE#
00045	NOUS HEAT PIPE AND ARTERY CONNECTOR	THERE FOR# CONTI
00042	UBE HEAT PIPE AND MEANS FOR CONTROL	THEREOF# DUAL T
00021	VING A SUBSTANTIALLY UNIDIRECTIONAL	THERMAL PATH# HEAT PIPE HA
00023	AR REACTOR#	THERMIONIC CONVERTER CELLS FOR NUCLE
00030	FUEL ELEMENTS FOR USE IN	THERMIONIC NUCLEAR REACTORS#
00043	HEAT	TRANSFER DEVICE#
00009	VAPORIZING HEAT	TRANSFER DEVICE#
00029	HEAT	TRANSFER SURFACE STRUCTURE#
00031	HEAT	TRANSFER TUBE ASSEMBLY#
00031	HEAT TRANSFER	TUBE ASSEMBLY#
00042	THEREOF# DUAL	TUBE HEAT PIPE AND MEANS FOR CONTROL
00019		UNDERWATER HEAT EXCHANGE SYSTEM#
00021	HEAT PIPE HAVING A SUBSTANTIALLY	UNIDIRECTIONAL THERMAL PATH#
00030	FUEL ELEMENTS FOR	USE IN THERMIONIC NUCLEAR REACTORS#
00033		VALVED HEAT PIPE#
00009		VAPORIZING HEAT TRANSFER DEVICE#
00037	HEAT PIPE WITH	VARIABLE EVAPORATOR#
00044	RITICAL POINT HEAT PIPE#	VEHICLE-HEATING SYSTEM EMPLOYING A C
00041	FLAT PLATE HEAT WITH STRUCTURAL	WICKS#
		*WITH * NOT INDEXED
00027	A ZERO CONTACT ANGLE WITH AN ALKALI	WORKING FLUID AND METHOD OF FORMING#
00027	RKING FLUID AND M/ CONDUIT HAVING A	ZERO CONTACT ANGLE WITH AN ALKALI WO

00016	BAER S C
00045	BAKKER L P
00021	BASIULIS A
00017	BASIULIS A
00023	BECKER R A
00040	BLOCK F G
00043	BUSSE C
00031	BUSSE C A
00030	BUSSE C A
00015	BUZZI U
00014	BUZZI U
00037	COLEMAN J B
00042	COLEMAN J B
00019	EDWARDS R N
00041	FELDMAN K T
00034	FELDMAN K T
00014	FIEBELMANN P
00013	FIEBELMANN P
00015	FIEBELMANN P
00011	FINKIN E
00033	FRANK S
00044	FRANK S
00036	FREGGENS R A
00031	GEIGER F
00012	GRITTON E C
00025	HAFSTAN L R
00040	HALL W B
00018	HARBAUGH W E
00036	HARRBAUGH W E
00035	HESS J L
00035	KESSLER S W
00031	KRAFT G
00010	KUN L C ET AL
00034	KUSIANOVICH J D
00038	LAZARIDIS L J
00039	LEFFERT C B
00046	LEFFERT C B
00024	LEFFERT C B
00025	LEFFERT C B
00033	LEVEDAHL W J
00026	MCHUGH K L
00022	MILTON R M
00029	MOORE R D
00015	NEU H
00014	NEU H
00013	NUE H
00012	PINKEL B
00031	POTZSCHKE M
00047	REIMERS E
00032	SASSIN W
00045	SOMERVILLE R H
00028	STUAB F W
00020	TRENT D S
00027	WEBSTER H F

00042	WELSCH J P
00009	ZUBER N ET AL

'BRIT ' NOT INDEXED
'PATENT ' NOT INDEXED
'S ' NOT INDEXED
'U ' NOT INDEXED

00013	BRIT PATENT 1220553#
00014	BRIT PATENT 1220554#
00015	BRIT PATENT 1220644#
00009	U.S. PATENT 3392781#
00010	U.S. PATENT 3454081#
00011	U.S. PATENT 3481439#
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00041	U.S. PATENT 3613778#
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00044	U.S. PATENT 3618854#
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00046	U.S. PATENT 3621906#
00047	U.S. PATENT 3622846#