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MASTER

NUCLEAR ROCKETS

U.S. ATOMIC ENERGY COMMISSION
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NUCLEAR ROCKETS

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Compiled by

Hugh E. Voress
Division of Technical Information, AEC

August 1968

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ABSTRACT

The compilation contains a total of 235 references to literature appearing in Nuclear Science Abstracts for 1966-67. Author and report-number indexes are provided.

INTRODUCTION

The concept of the nuclear rocket was considered soon after World War II following the success of the German V-2 long-range ballistic missile. However, no studies as to the feasibility of nuclear energy in space application were undertaken until 1955, when the KIWI Program was established. By 1959, KIWI Reactor tests had shown significant performance and had established the potential of the nuclear rocket. In 1961, a national nuclear space propulsion program, SNPO (Space Nuclear Propulsion Office), was created to direct future developments. Currently, steady progress is being made in overcoming the many technical problems involved in the development of the nuclear rocket.

This bibliography covers the literature cited in Nuclear Science Abstracts during 1966 and 1967. The individual references are arranged by issuing agency, and author and report-number indexes are included. The US AEC reports cited are available from the Clearinghouse for Federal Scientific and Technical Information, U. S. Department of Commerce, Springfield, Virginia 22151, for \$3.00 each or \$0.65 in micronegative form.

REFERENCES

Aerojet General Corp., Azusa, Calif.

1 (CONF-651101-61) CRYOGENIC IRRADIATION OF RESISTANCE TEMPERATURE TRANSDUCERS FOR NERVA. Greenhow, W. A.; Schenz, R. F.; Gilchrist, E. J. (Aerojet-General Corp., Azusa, Calif.). Nov. 1965. Contract SNP-1. 25p. Dep. mn. CFSTI \$1.00 cy, \$0.50 mn. From 13th Conference on Remote Systems Technology, Washington, D. C.

Eighteen platinum-wire resistance-temperature transducers (RTT) of six different design configurations, (wire diameter 0.3 to 2.0 mils) were irradiated in LH_2 at the Gound Test Reactor (GD/FW) while being maintained at -423°F . The integrated neutron exposure ranged from 3.1×10^{16} to 2.2×10^{17} nvt ($E > 1.0$ Mev). The resistance of the RTT sensing element was measured periodically and correlated to temperature-measurement error. The results of these tests followed closely the predicted temperature-measurement deviations (2 to 8°F). The calculations and analyses performed indicate that the change in platinum sensing element resistance is due to interstitials resulting from recoil-proton bombardment in the LH_2 which surrounds the platinum sensing elements. Since the recoil protons have a range of 10^{-4} cm in platinum, a surface defect results which has a greater influence on the resistance of the smaller diameter wire. Based on analytical and experimental data, the optimum design for RTT sensing element wire diameter is 1.0 mils (auth)

2 NUCLEAR ROCKET ENGINE CONTROLS. Sheridan, E. A. (Aerojet-General Corp., Sacramento, Calif.); Kirschbaum, H. S. New York, American Institute of Aeronautics and Astronautics, 1966, Preprint No. 66-1005, 10p., \$1.50. (CONF-661124-2). DTIC.

From 3rd AIAA Annual Meeting, Boston.

A nuclear rocket engine requires controls for reactor power, nozzle chamber temperature and pressure. Control of these parameters is required during three phases of operation. During Startup and Bootstrap nuclear power is brought from neutron source power level to an intermediate level by open loop programming. At this point, the power range controllers are used to initiate the flow of coolant and increase reactor power until chamber temperature and pressure are increased to a predetermined level. The Power Range phase of operation is then begun. Pressure control in the Power Range is accomplished by positioning the valve which regulates drive gas to the turbopump with a closed loop controller. The temperature has historically been controlled with a closed loop temperature controller which works through an inner nuclear power loop to position the control drums. Recent experiments have demonstrated that the inner power loop may be omitted and also that temperature changes may be controlled by varying the coolant flow. This is feasible because of the basic stability of the nuclear engine. It has resulted in startups to operating power with fixed control drum position. The third phase of operation consists of Shutdown and Cooldown. This phase uses different controllers to introduce coolant which then removes the reactor decay heat (auth)

3 MULTIPLE EXHAUST NOZZLES FOR NUCLEAR ROCKET ENGINES. Vanica, D. F.; Duke, E. E. (Aerojet-General Corp., Sacramento, Calif.). New York, American Institute of Aeronautics and Astronautics, 1966, Preprint No. 66-925, 10p., \$1.50. (CONF-661124-3). DTIC.

From 3rd AIAA Annual Meeting, Boston.

Results of theoretical and experimental studies conducted to evaluate the performance of nuclear rockets using multiple exhaust nozzles are presented. Analytical procedures for nozzle design and performance predictions are developed. Aerodynamic efficiency of the experimental model is shown to be lower than an equivalent single nozzle because of the thrust vector cosine losses, however the concept offers a significant advantage in vehicle payload capacity when applied to nuclear rockets. Convective cooling requirements are reduced by using refractory nozzle materials so that less pump work is required, hence less turbine bleed flow, which increases the available propellant for thrust conversion. Also, less heat is extracted from the exhaust gases because of the reduced cooling requirements. The most significant advantages, however, are the performance gain which occurs because of the high temperature capability of the refractory nozzles and the greater propellant capacity for the same overall stage length as a result of shortening the engine. (auth)

4 (N-66-13124) DESIGN SPECIFICATION (ENGINE, ROCKET, NUCLEAR) FOR XE-1, NERVA PROGRAM. Landesberg, E. (Aerojet-General Corp., Sacramento, Calif.). Mar. 1965. Contract SNP-1. 38p. (NASA-CR-68622; AGC-90016; RN-DR-0020). CFSTI \$2.00 cy \$0.50 mn.

Design specifications are given for the hot-bleed, shielded, XE-1 configuration of the ground test experimental version of the NERVA engine series. This engine is suitable for static firing tests (300 sec max) with the engine oriented in a nozzle-down position. Specifications are given for the following major subsystems: reactor and thrust chamber assemblies; external shield; and propellant feed, emergency cooldown, pneumatic, control, and diagnostic instrumentation systems (STAR)

5 (N-66-13125) [STUDIES OF THE NERVA PROGRAM] Quarterly Report No. 3, April-June 1965 (Aerojet-General Corp., Sacramento, Calif.). Sept. 30, 1965. Contract SNP-1. 298p. (NASA-CR-68623; RN-Q-0036). CFSTI \$6.00 cy, \$1.50 mn.

Progress in the NERVA engine development program and its associated tasks is reported. The material is presented in a precise summary manner; and includes developments in the following areas: engine system, propellant feed system, reactor system integration, thrust chamber assembly, engine controls, systems analysis, radiation effects program, remote handling equipment, ground support equipment, instrumentation, ground operations safety, product assurance, non-fuel materials, and exhaust system (STAR)

6 (N-66-26757) CENTERBODY DIFFUSER STUDY. (Aerojet-General Corp., Sacramento, Calif.). Oct. 1965. Contract SNP-1. 124p. (NASA-CR-75221; RN-S-0243). CFSTI \$3.00 cy, \$0.65 mn.

In order to determine the feasibility of water-cooled centerbody diffusers for nuclear rocket application, nine different scale model centerbody configurations were fabricated and tested. The models included three nose cone sizes, and for each nose cone size three different cone frustums were designed, the nose cones varied by the magnitude of their half-angle. Testing was conducted using the pressure blowdown system in series with a large stored energy heater to supply the gaseous nitrogen to the $1/15$ size NERVA II nozzle. For the range tested, nose cone angles and radii seemed to have no noticeable influence on the ejector starting pressure. With the use of a correlation factor of 1.15, the starting pressure

ratio can be predicted by means of the conventional normal shock theory. It was proven that a full scale, water-cooled centerbody diffuser can be built. A theoretical investigation of heating rates involving the spherical tip, the cone frustrum, the transition point cone-to-sphere, and the mounting struts of the centerbody for laminar and turbulent flow revealed that the absolute maximum heating rate is located at the sonic point, i.e., a spot on the spherical segment under turbulent flow conditions about 41° from the forward stagnation point (STAR).

7 (TID-22929) PERFORMANCE CHARACTERISTICS OF ETS-1 NUCLEAR EXHAUST SYSTEM. NERVA PROGRAM. (Aerojet-General Corp., Azusa, Calif.). Oct. 1964. Contract SNP-1. 78p. (RN-S-0099(Rev.)). Dep. mn. CFSTI \$3.00 cy, \$0.65 mn.

An ejector system for Engine Test Stand-1 (ETS-1) at Nevada Rocket Development Site (NRDS) was selected at the completion of the testing and analysis program of CY 1963. During the CY 1964 program, this selected ejector system was subjected to a series of system performance analysis tests to provide an operational map, as well as a high level of confidence in the prediction of operation of the Nuclear Exhaust System (NES) at NRDS. Ejector system performance analysis tests were first conducted using a 1/8 scale model system. A 1/4-scale model ejector system was built and tested to verify the scaling parameters used and, consequently, to increase the confidence level of the performance predictions of the full-scale ejector system. The data were analyzed and compared with the 1/8-scale data. Data agreement was considered to be very good in all areas, therefore, there is high confidence in the prediction of performance and operation of the NES at NRDS (auth).

8 (TID-23639) TRANSIENT ENGINE SIMULATION PROGRAM. NERVA PROGRAM. (Aerojet-General Corp., Azusa, Calif.). Aug. 1964. Contract SNP-1. 220p. (RN-S-0114). Dep. mn. CFSTI \$3.00 cy, \$0.65 mn.

The Transient Engine Simulation Program showing logic, the derivation of equations and operating instructions are given. The program calculates metal and fluid temperatures and stagnation pressure distributions as functions of time and distance. The overall engine system is represented by combining several separate existing mathematical models of engine subsystems (e.g., turbopump, reflector, shield, core, nozzle, hot-bleed port). The program is general and capable of handling design modifications. Program accuracy is shown to be a direct function of input. Good agreement with NRX-A1 and other test data has been shown. The program is in production and is coded in SCAT for the IBM 7094 computer using the Aerojet Kismet monitor (auth).

9 (TID-23648) NES/ETS-1 DUCT STRUCTURAL DYNAMICS. NERVA PROGRAM. (Aerojet-General Corp., Sacramento, Calif.). Aug. 1965. Contract SNP-1. 108p. (RN-S-0211). Dep. mn. CFSTI \$3.00 cy, \$0.65 mn.

The final structural dynamics analysis of the Nuclear Exhaust System (NES) duct for the Engine Test Stand No. 1 (ETS-1) at NRDS is presented. The duct assembly is designated SST-2, subsonic turn configuration. Using digital computer techniques, structural vibration modes and natural frequencies of the exhaust duct assembly were obtained. Dynamic stresses along the duct section under full scale nuclear (NERVA) engine operation were calculated. As a result of this analysis the structural dynamic integrity as well as the overall structural design stability has been proven to be adequate for the NES for ETS-1. (auth)

10 (TID-23649) INSTRUMENTATION EVALUATION NRX-A2 TESTS. NERVA PROGRAM. (Aerojet-General Corp., Sacramento, Calif.). Feb. 1965. Contract SNP-1. 118p. (RN-S-0193). Dep. mn. CFSTI \$3.00 cy, \$0.65 mn.

The performance evaluation and pre- and post-test evaluation of the Aerojet-General Corporation NRX-A2 Instrumentation Kit is covered in this report (auth).

11 (TID-23650) NES EXHAUST PLUME SCALE-MODEL MEASUREMENTS AND FULL-SCALE PREDICTIONS. NERVA PROGRAM. (Aerojet-General Corp., Azusa, Calif.). Nov. 1964. Contract SNP-1. 29p. (RN-S-0168). Dep. mn. CFSTI \$3.00 cy, \$0.65 mn.

The predicted full-scale NES exhaust plume length and exhaust plume thermal radiation flux at proximate surfaces, and the methods used to predict full-scale flame length and thermal radiation from scale-model data are described. Also presented are experimental values of scale-model NES exhaust-plume length, exhaust-plume thermal radiation flux at proximate surfaces, and exhaust-plume emittance (auth).

12 (TID-23651) PERFORMANCE CHARACTERISTICS OF ETS-1 NUCLEAR EXHAUST SYSTEM. NERVA PROGRAM.

(Aerojet-General Corp., Azusa, Calif.). June 1964. Contract SNP-1. 53p. (RN-S-0099). Dep. mn. CFSTI \$3.00 cy, \$0.65 mn.

Test results of the ejector scale model test program as they apply to the full scale Engine Test Stand-1 (ETS-1) are presented. The evaluation concerns the performance envelope for the selected subsonic turn ejector system in the Nuclear Exhaust System (NES) for the ETS-1. The experimental tests were conducted on 1/8 scale models. As a result of the data obtained through this experimental and analytical evaluation, the design implications for the NES for ETS-1 have been drawn (auth).

13 (TID-23652) A HEAT TRANSFER INVESTIGATION OF EJECTOR SYSTEMS WITH 90° TURNS. NERVA PROGRAM. (Aerojet-General Corp., Sacramento, Calif.). Nov. 1964. Contract SNP-1. 25p. (RN-DR-0038). Dep. mn. CFSTI \$3.00 cy, \$0.65 mn.

Results are presented from a test program that evaluated the heat transfer characteristics of a series of ejector systems that turned the rocket exhaust gases through 90°. The ejector systems covered a range of designs that utilized both subsonic and supersonic turning of the gases within a fixed height. A series of tests with heated nitrogen was made for each ejector, during which measurements of local pressures and wall temperatures were made to provide the data necessary to evaluate the heat-transfer conditions. The results from three of these systems are discussed to illustrate the differences in thermal behavior that can be obtained during the turning of the gases. The maximum heating rate was reduced by a factor of 7 when the ejector had a long radius, as compared to a short radius 90° turn and by a factor of 5 by permitting the gases to shock down to subsonic flow prior to entering the short radius bend. A method of converting the scale-model heat-transfer coefficient data to any other scale size, working fluid, nozzle chamber temperature or chamber pressure and an empirical correlation of the maximum heating rates is presented (auth).

14 (TID-23653) DEVELOPMENT OF NERVA COPPER-CONSTANTAN IMMERSION THERMOCOUPLES. NERVA PROGRAM. (Aerojet-General Corp., Sacramento, Calif.). Dec. 1964. Contract SNP-1. 104p. (RN-DR-0044). Dep. mn. CFSTI \$3.00 cy, \$0.65 mn.

The development of immersion type copper-constantan thermocouples for NRX A2 testing is reported. All significant analyses and testing performed during the development of the copper-constantan thermocouples and the test results are described (auth).

15 (TID-23654) NUCLEAR ENGINE ANALYSIS PROGRAM. VOL. I. TECHNICAL DISCUSSION AND PROGRAM NOMENCLATURE. NERVA PROGRAM. (Aerojet-General Corp., Azusa, Calif.). Dec. 1964. Contract SNP-1. 140p. (RN-S-0171). Dep. mn. CFSTI \$3.00 cy, \$0.65 mn.

The Nuclear Engine Analysis Program is an IBM 7094 digital computer program which simulates the steady-state operation of the NERVA hot-bleed engine over the full operational range of chamber pressures and temperatures. This program computes the energy balances for all engine components and for the entire engine, as required to satisfy the demanded chamber pressure and temperature. The program output consists of temperatures, pressures, and flow rates throughout the system. In addition, program output such as the turbine inlet temperature, turbine flow rate, hot-bleed flow rate, diluent flow rate, turbopump speed, pump specific speed, turbine power control valve position, nuclear power, engine thrust and specific impulse is obtained. The program is presently in production status and is being used extensively for steady-state analyses of the NERVA engine systems (auth).

16 DEVELOPMENT PROBLEMS OF NUCLEAR ROCKET ENGINES. Beveridge, J. H. (Aerojet-General Corp., Sacramento, Calif.). Ann. N. Y. Acad. Sci., 134: 304-16 (Nov. 22, 1965).

The development and testing of the NERVA engine are briefly discussed. The major technical problems of the nuclear rocket engine are stressed together with solutions to these problems (D.C.W.)

17 DEVELOPMENT OF A TITANIUM PRESSURE VESSEL FOR NERVA. Snyder, C. R. (Aerojet-General Corp., Sacramento, Calif.). J. Spacecraft Rockets, 3: 437-9 (Mar. 1966).

The development of a titanium pressure vessel for NERVA reactors is briefly discussed with emphasis on the materials studies and fabrication studies that were performed. The bases for the selection of the Al-Sn-Ti alloy that was used are summarized (D.C.W.)

18 NOZZLE TUBE-WALL TEMPERATURE MEASUREMENT BY RADIOMETRIC TECHNIQUES. Geery, E. L. (Aerojet-General Corp., Sacramento, Calif.); Thompson, W. R.; Beveridge, J. H.; Helm, W. J. J. Spacecraft Rockets, 3: 1144-6(July 1966).

A radiometer mounted on the outside of a rocket nozzle window is described for viewing the cooled side of the heated wall through the coolant (LH₂) flow without disturbing the hot gases or coolant. The radiometric device measures at more than two wavelengths, employs a single detector, operates in the near-infrared region, and is capable of continuous measurement. (J R D)

Air Force Academy, Colorado

19 AN EFFECT OF NUCLEAR-REACTOR OPERATION IN SPACE. Carpenter, Donald G.; Denfeld, Richard E.; Kronlund, Kenneth H. (Air Force Academy, Colo.). Nature, 209: 64(Jan. 1, 1966).

The effects of space environment on a reactor system are considered. It is suggested that the reactor system might achieve a noticeable positive potential while in operation. The magnitude of this effect was determined from some rough approximations. For a 1 Mw(t) reactor in a polar orbit at 1000 km the electrostatic energy stored was calculated to be 100 joules. (M C G)

Air Force Institute of Technology, Wright-Patterson AFB, Ohio. School of Engineering

20 (AD-635232) SN TRANSPORT CALCULATIONS FOR A GASEOUS CORE REACTOR. Bloemker, Carl F. (Air Force Inst of Tech., Wright-Patterson AFB, Ohio. School of Engineering) Mar 1966 104p (GSP/PH-66-1) CFSTI \$6.00 cy, \$0.75 mn Thesis

A nuclear analysis was performed on a gaseous core cavity reactor suitable for space propulsion. The system consisted of a spherical gaseous core reactor surrounded by a C-Be reflector. To carry out this analysis, the angular segmentation (Sn) method was applied to the conservative form of the Boltzmann Equation to obtain a set of finite difference equations. The finite difference equations were then incorporated into a computer code. The computer code was programmed for the IBM 7094 coupled system using Fortran IV. The code was first applied to an idealized gas core reactor. The difference in critical mass from a previous calculation was 8%. After this check on the reliability of the code, a parametric study on the gaseous core reactor was performed. The results of this study, which determined the critical mass as a function of core radii and design thrust, are presented. (auth)

Argonne National Laboratory, Illinois

21 (ANL-7055, pp 177-212) REACTOR SAFETY. Baker, L. Jr.; Tevebaugh, A. D. (Argonne National Lab., Ill.).

Results of studies concerning metal-water reactions are reported along with results of investigations relating to fast reactor safety. Information is included on Al-steam reactions, laser-induced metal-water reactions, radio-induced metal-water reactions, metal-water reactions in TREAT and reaction calculations. Information is also included on reactions of liquid Na with reactor materials, heat transfer, and Na-air reactions. (J R D)

22 (ANL-7099) STUDY OF REFLECTOR-BASED CONTROL OF FAST NUCLEAR ROCKET REACTORS. Almenas, K. K. (Argonne National Lab., Ill.). May 1966. Contract W-31-109-eng-38. 82p. Dep. mn. CFSTI \$3.00 cy, \$0.65 mn.

A comparative evaluation of a variety of reflector and control materials suitable for use with fast-spectrum, high-performance cores was carried out. The evaluation focused primarily on the control potential of reflector-located control mechanisms, though factors such as weight, volume, and critical mass savings were also considered. It was determined that for most fast-spectrum core-reflector combinations a well-defined optimum control-vane design exists. The dependence of this optimum control span on control-vane thickness and composition was explored in detail. Computational methods for determining the optimum vane configuration and such ancillary but important aspects as control-vane heating are presented. (auth)

23 (ANL-7110, pp 99-229) FAST REACTORS. (Argonne National Lab., Ill.).

A number of experimental and theoretical studies of the physics of fast reactors, including rocket reactors, were carried out. Safety studies were also performed, and a set of programs was developed for criticality calculations. Several fuel systems were studied. (D C W)

24 (ANL-7110, pp 311-401) MISCELLANEOUS. (Argonne National Lab., Ill.).

Efforts were made to extend and improve the accuracy of general reactor physics, with emphasis on resonance absorption and scattering effects. Codes and methods for reactor physics calculations were developed, together with methods for evaluating mathematical functions. A rotating electric power generation system was evaluated, and the efficiency of nuclear pumping of a laser was studied, along with the amplification of gamma photons by nuclear pumping. Thermionic energy conversion with a plasma thermocouple was investigated, as was the vaporization of sodium in coolant channels. The effects of the thermal properties of UO₂ on the dynamics of fast reactors were studied, and methods were developed for determining the stress distributions in fuel elements. The thermophysical properties of reactor materials at high temperatures were also studied. (D C W)

25 (ANL-7125, pp 150-99) REACTOR SAFETY. Baker, L. Jr.; Tevebaugh, A. D.; Bingle, J. D. (Argonne National Lab., Ill.).

Studies relating to the safety of fast reactors and of metal-water reactions are reported. The chemical reactions are being studied so that realistic estimates can be made of the rates and extents of reactions during hypothetical reactor accidents. Methods used to study the reactions included isothermal reaction rate determinations, nonisothermal studies of the reactions with fine metal particles, in-pile meltdown experiments with specimens of typical reactor fuel materials, and heat experiments designed to simulate the conditions experienced by fuel elements during a loss-of-coolant accident. For reactor safety, a survey study was made of chemical and physical interactions of fuel and cladding materials at high temperature with molten sodium. Emphasis was given to detecting and evaluating exothermic alloying reactions and interactions that result in extensive break-up or frothing. (P C H)

26 (ANL-7190, pp 11-142) REACTOR PROJECTS AND PROGRAMS. (Argonne National Lab., Ill.).

Activities associated with the EBR-II are summarized. Information is included on approach-to-power program, plant improvements, and experimental support. The fast reactor test facility is described, and research in support of this facility is summarized. Information is presented concerning component design and testing, design of in-cell fuel and equipment handling systems, and safety analyses results. The history and status of the Argonne Advanced Research Reactor (AARR) are reviewed. Information is included on design of the AARR and on supporting research and development. Research on the Experimental Boiling Water Reactor is reported under plant modification, inspection, maintenance, and supporting research and development. Stress analysis of the CP-5 vessel coolant distribution plenum is reported. The Argonne nuclear rocket program is described. Information is included on system analysis, fuel element development, operations at the H₂ flow facility, and research on structural mechanics. (J R D)

27 (ANL-7290, pp 123-38) ARGONNE NUCLEAR ROCKET PROGRAM. (Argonne National Lab., Ill.).

A summary of developments in the Argonne Nuclear Rocket Program, terminated in July 1966, is presented. The unclassified parts of the design for a 10,000-lb-thrust system are summarized. Structural mechanics test facilities and analytical models are discussed briefly. The analysis of thermal stresses in fuel element coolant channels is outlined. The design of a multipurpose high-temperature model testing furnace facility, which was under construction at termination, is presented. (M L S)

28 (ANL-7320, pp 186-93) MEASUREMENTS AND ANALYSIS OF Al-, Al₂O₃-, AND BeO-REFLECTED FAST CRITICAL EXPERIMENTS. Butler, D. K.; Doerner, R. C.; Knapp, W. G. (Argonne National Lab., Ill.).

The series of critical assemblies discussed was performed in connection with the program for development of a fast W reactor.

for nuclear propulsion. A program of critical experiments was planned to obtain some basic information about fast W-based systems. The approach selected was to begin with systems which had already been studied, such as Assemblies 11 and 22 of ZPR-3 and Assembly 1 of ZPR-6. A series of critical configurations was constructed in which only a single change of composition was made from one assembly to the next. The experiments were performed with the split-bed assembly ZPR-9. The cores were made as close approximations to cylinders as possible in the rectangular drawers of the assembly. Criticality was normally achieved by varying the core radius. In each assembly a number of measurements were made. In addition to criticality, determinations of fission-rate distribution, neutron lifetime, and central and spatial reactivity worths were made. Some time was also spent studying properties related to control, including the effect of inserting a ring of B into the reflector near the core boundary. Included are criticality, the spatial distribution of fission rates, and the worths of various materials at the core center and as a function of radius. (auth)

29 THEORETICAL AND EXPERIMENTAL PHYSICS STUDIES OF TUNGSTEN BASED NUCLEAR ROCKETS. Butler, D. K.; Doerner, R. C.; Knapp, W. G.; Loewenstein, W. B. (Agronne National Lab., Ill.). New York, American Inst. of Aeronautics and Astronautics, 1966, Paper No. 66-586, 8p., \$1.50. (CONF-660608-8). ORAU.
From 2nd AIAA Propulsion Joint Specialist Conference, Colorado Springs.

Physics studies in support of the design of a W metal based, UO_2 fueled, Be reflected rocket reactor are reported. Two lines of study were followed. The first was designed to provide basic information for understanding the neutronic properties of this type of reactor. A series of critical assemblies, each differing from its predecessors in only one significant way, provided parameters important to rocket applications. W based cores fueled by U metal and simulated UO_2 with reflectors of Al, Al_2O_3 , and BeO were included. Measurements included critical dimensions, fission and reaction rates, spatial reactivity-worth distributions and neutron lifetimes. Material replacement experiments for fissile and core structural material (e.g. W and Re) as well as a variety of other materials of interest represented a major effort. Calculations in conjunction with the experimental work emphasized the assembly of nuclear data and the testing of the calculational techniques with diffusion and transport theory in both one and two dimensions. The second line of study was in direct support of the design effort. It included calculation of the properties of proposed systems and the development of simplified calculational techniques for use in combined engineering and physics parametric studies. (auth)

Arizona University, Tucson

30 (CONF-650413, pp 164-81) SYNTHESIS OF OPTIMAL FEEDBACK CONTROL FOR NUCLEAR-ROCKET-ENGINE START-UP. Secker, Phillip A.; Weaver, Lynn E. (Arizona Univ., Tucson. Dept. of Nuclear Engineering).

Linear optimal feedback control theory is applied to the synthesis of an optimum nuclear-rocket-engine startup program by use of a model-following system. This theory generates a feedback program of linear gains that alter the plant dynamics such that the rocket-engine response approaches that of the model. If small perturbations are taken about the optimum trajectories, the system differential equations become linear with time-varying coefficients. The optimum feedback control minimizes an integral quadratic performance index containing system errors and control motions. Analog-computer studies show the effect of this synthesis technique in minimizing the system error due to the disturbances and the nonexact mathematical description of the system. (auth)

31 (N-65-21462) RESEARCH IN AND APPLICATION OF MODERN AUTOMATIC CONTROL THEORY TO NUCLEAR ROCKET DYNAMICS AND CONTROL. VOLUME II. Semiannual Status Report, September 1, 1964-February 1, 1965. Melsa, James L., Schultz, Donald G. (Arizona Univ., Tucson. Dept. of Nuclear Engineering). Mar. 1965. 165p. (NASA-CR-62187). CFSTI \$5.00 cy, \$1.00 mn.

The second method of Liapunov is used as a basis for developing a method of closed-loop time-optimal control of linear systems with bounded control norm. The second

method is combined with the minimum principle in an optimization approach centering on a special class of solutions for the Hamilton-Jacobi equations. When these solutions, called eigenvector scalar products, are used for the control of systems in which the control matrix is nonsingular, it is possible to find surfaces which bound the optimal isochrones in an unusually simple manner. When the control matrix is allowed to be singular, it is no longer possible to develop a single method, effective suboptimal control is obtained by using the Bang-Coast method and the switched control method. Procedures are outlined for applying these suboptimal methods to some practical control problems, and two simple nuclear rocket control problems are used as illustrations. In each case, the method is shown to represent an effective compromise between system complexity and speed of response. (STAR)

32 (N-66-23593) RESEARCH IN AND THE APPLICATION OF MODERN AUTOMATIC CONTROL THEORY TO NUCLEAR ROCKET DYNAMICS AND CONTROL. VOL. II. Semiannual Status Report. Higgins, Walter T. Jr.; Schultz, Donald G. (Arizona Univ., Tucson. Dept. of Nuclear Engineering). Mar. 1966. 152p. (NASA-CR-74134). CFSTI \$3.00 cy, \$0.65 mn.

The Second Method of Liapunov, the Popov frequency criterion and the matrix inequality method were used to study the stability of certain nonlinear and/or time dependent control systems. The types of systems considered are described and stability definitions and theorems of the Second Method are given. The Liapunov function used is of the Lurie type, i.e., a quadratic for the state variables plus the integral involving the nonlinearity. The use of a quadratic Liapunov function without the integral for a system with a single time dependent element is shown and it is pointed out that the inclusion of the integral results in a Liapunov function which is no longer $V(x)$ but is $V(x, t)$. The matrix inequality method was extended for systems with more than one nonlinearity or time dependent element. This allows stability criteria which are analogous to criteria for single element systems to be derived for polynomial systems. (STAR)

33 (NASA-CR-70862) RESEARCH IN AND APPLICATION OF MODERN AUTOMATIC CONTROL THEORY TO NUCLEAR ROCKET DYNAMICS AND CONTROL. VOLUME I. Semi-Annual Status Report. Weaver, Lynn E., Shultz, Donald G.; Melsa, James L., Secker, Philip A., Nordal, Donald M.; Slivinsky, Charles R. (Arizona Univ., Tucson. Engineering Research Lab.). Feb. 1966. 316p. CFSTI \$3.00 cy, \$0.65 mn. Includes N-66-19882 through N-66-19885.

Optimal control theory is applied to derive analytical expressions for compensating reactivity control which minimizes an integral quadratic performance index containing system errors and control motions. Various linear and nonlinear reactor models are analyzed. Analog computer studies show the effect of quasi-optimal feedback control in minimizing system errors caused by internal disturbances. In other research the second method of Liapunov is used to analyze the behavior of high-order control systems. This is accomplished by finding a lower order model whose response closely approximates the response of a higher order system. The model is developed by matching the surfaces described by Liapunov functions of the system and the model. In particular a second-order model and a third-order model are developed which provide good results for all systems investigated. The second-order model is shown to be similar to the model obtained using phase margin techniques, and of greater importance, the third-order model is shown to be a better approximation to systems than the phase margin and the second order models. Thus this method serves to extend the practical usefulness of the second method from mere stability analysis to relative stability analysis (response of the system) and synthesis. Aspects of the design of optimal feedback systems for linear systems subject to quadratic integral performance criterion are examined with emphasis on regulator and servomechanism problems. In the regulator problem the optimal design is shown to be a weighted constant feedback of all state variables. For the servomechanism problem the solution consists of a regulator plus a linear prefilter system. Methods are presented for both the exact and approximate solution of both problems. (J R D)

34 THE STABILITY OF COUPLED-CORE NUCLEAR REACTOR SYSTEMS BY THE SECOND METHOD OF LIAPUNOV [Thesis] Murray, Hugh Sutherland. Tucson, Ariz., Univ. of Arizona, 1965. 105p.

The type of coupled-core system studied includes two or more separate power reactors coupled together for the purpose of achieving an increased system power output. The primary example is that of the proposed clustering of nuclear rocket engines. The equations that describe the

dynamics of a coupled-core system contain, because of a time lag in the interdependent portion of the system behavior, variables whose arguments are delayed or retarded in time. It is necessary from a practical standpoint to discover whether or not a projected coupled-core system is inherently stable. Recently, researchers have found that the most universal method of investigating the stability of ordinary differential equations is the Second Method of Liapunov. The Second Method is directly applicable to nonlinear equations. The presence of the time delay, however, necessitates some modifications to the Liapunov approach. The extension of the method is based upon the work performed by Driver, Krasovskii, and Razumikhin on the mathematical features of equations with delay. The time delay is incorporated directly into the Second Method, thus it is certain that the results are conservative due to the sufficiency of the stability conditions. The modified approach is based upon comparing all possible solutions of a system with delay with the known properties of the system without delay. The technique used is to find quadratic Liapunov functions for the linearized, zero-delay system. Stability conclusions can then be made for the linearized system with delay. Finally, the nonlinear terms are added to estimate the regions of stability of the state variables. The results are adequate, from a practical viewpoint, for a simplified two-core example. However, the approach becomes highly restrictive for higher order, more complicated cases, and the results become marginal. The basic stability conclusions combined with simulation studies for the more complicated system, reveal that there are no practical stability problems involved in coupled-core nuclear reactor dynamics. (Dissertation Abstr.)

Atomic Energy Commission

35 COUPLED REACTORS IN NUCLEAR ROCKET APPLICATIONS. Johnson, Paul G. (AEC-NASA Space Nuclear Propulsion Office, Washington, D. C.). pp 11-28 of Coupled Reactor Kinetics. Chezem, C. G.; Koehler, W. H. (eds.). College Station, Tex., Texas A and M Press, 1967. From American Nuclear Society, Coupled Reactor Kinetics Conference, College Station, Tex., Jan. 23-24, 1967. See CONF-670107.

The use of clustered reactors for space applications is discussed. Requirements of manned planetary mission requirements are given. Shielding problems involved in engine cluster are summarized. 3 references. (M.L.S.)

36 RADIOLOGICAL PREDICTION AND MONITORING OF TESTS AT THE NUCLEAR ROCKET DEVELOPMENT STATION. Griffiths, P.; Erickson, P. B. (Space Nuclear Propulsion Office, Nevada). IEEE (Inst. Elec. Electron. Eng.), Trans. Nucl. Sci., NS-13: No. 1, 6-13 (Feb. 1966).

The procedure and formula used in the radiological analysis of reactor testing at the Nuclear Rocket Development Station are described. Monitoring methods are discussed, and a comparison is made between measured dose levels and guide values. (auth)

37 REACTOR DEVELOPMENT AND TECHNOLOGY. pp 3-101 of Fundamental Nuclear Energy Research. Washington, D. C., U. S. Atomic Energy Commission, 1965.

Research is summarized concerning reactor fuels and materials, reactor physics, reactor instrumentation and heat exchange, processing for recovery of fissionable materials from spent fuels, breeder reactors, and nuclear safety. (J R D)

Atomic Power Development Associates, Detroit

38 AN ANALYSIS OF THE KIWI-TNT EXPERIMENT WITH MARS. Klickman, A. E.; Hirakawa, N. (Atomic Power Development Associates, Inc., Detroit). Trans. Amer. Nucl. Soc., 10: 246 (June 1967).

From 13th Annual Meeting of the American Nuclear Society, San Diego, Calif., June 11-15, 1967. See CONF-670602.

Battelle Memorial Institute, Columbus, Ohio

39 (NP-15823) DEVELOPMENT OF A MODEL EXPERIMENTAL DESIGN FOR NERVA INSTRUMENTATION RADIATION-EFFECTS TESTS. Drennan, James F.; Cote, Roger W.; Wyler, Eugene N. (Battelle Memorial Inst., Columbus, Ohio) July 19, 1965. 103p.

To demonstrate the application of experimental design principles to the radiation-effects program pertaining to the development of instrumentation for the NERVA environment, a model design based on the test for a LVDT linear displacement transducer described in Test Document 23/W205 was prepared. For this model experimental design, one experimental problem concerns determining whether the transducer internal temperature will remain within acceptable limits at the level of radiation flux expected for the NRX-A3 application, another pertains to establishing whether or not the transducer performance parameter values will meet the NERVA requirements at the level of integrated fast-neutron exposure expected for NRX-A3 use. A data reduction and analysis procedure based on regression techniques was developed and verified. The analysis procedure yields statements of the probability of successful transducer performance and the confidence appropriate to these statements. The precision and accuracy required for the experimental measurements and the experimental procedure were defined. The mechanics of the experimentation were summarized as a test specification. Although the model experimental design is directed toward specific problems and a specific instrument, its format and logic are applicable generally to radiation-effects testing of instrumentation. It is believed that the data reduction and analysis procedures documented may be applicable in detail to a wide variety of the radiation-effects experiments that will be planned during the NERVA development program. (auth)

Bendix Corporation, Southfield, Mich. Research Labs

40 (NASA-CR-54758) REPLACEMENT OF ELECTRONICS WITH FLUID INTERACTION DEVICES. Summary Report, Task-1. Cardon, M. H. (Bendix Corp., Southfield, Mich. Research Labs, Div.). Aug. 31, 1965. Contract NAS 3-6201. 160p. (BRLD-2946).

Efforts devoted to design and analysis of an actuation system that uses fluid circuits instead of electronics are discussed. The objective is to develop an all-pneumatic servo actuator with performance equal to the electro-pneumatic unit and with greater reliability in adverse environments. The system is designed to use a piston-cylinder with rack and pinion that produces 180° rotary output. Design features include a 6 cps bandwidth, 0.2 degrees resolution, and 300 in.-lb stall torque. The working fluid is dry H₂ with 215 psia supply and 50 psia exhaust. Experimental data on vortex amplifiers for this system are included. (auth)

41 (NASA-CR-54776) FABRICATION AND TEST OF A FLUERIC POSITION SERVO. Quarterly Report, June 10-September 10, 1965. (Bendix Corp., Southfield, Mich. Research Labs, Div.). Contract NAS-3-6201. 19p. (BRLD-3133). CFSTI \$1.00 cy, \$0.50 mn.

A layout drawing defining the mechanical configuration of a flueric circuit was completed, and a breadboard vortex amplifier was designed and built. A brief description of the actuation system previously designed is included. (P.C.H.)

42 (NASA-CR-54788) PNEUMATIC NUTATOR ACTUATOR MOTOR. Final Report. Howland, G. R. (Bendix Products Aerospace Div., Bendix Corp., South Bend, Ind.). Oct. 17, 1965. Contract NAS-5214. 138p. (BPAD-863-16719R).

The design, development, and test of a new type of low-speed, high-torque motor designed for manipulating the control drums of nuclear rocket engines similar to NERVA are described. The motor consists of a pair of bevel gears with an unequal number of teeth. Rotational output is obtained from nutational motion of the input gear driven by pressurized bellows located around its periphery. Flow to

the bellows is commutated by vortex amplifiers operating in a closed loop logic sequence. The pneumatic logic circuit operates without moving mechanical parts (auth)

43 (BRLD-3255) FABRICATION AND TEST OF A FLUERIC POSITION SERVO. Quarterly Report, September 10, 1965-December 10, 1965. (Bendix Corp., Southfield, Mich. Research Labs. Div.). Contract NAS 3-6201. 52p. (NASA-CR-54900).

Further developments on the pneumatic control drum actuator for a nuclear rocket engine in which the electronics were replaced by flueric devices are reported. The designs of the Position Error Detector Unit and Power Control Valve were completed. Breadboard vortex valves, single input amplifiers and summers were built and tested. The lead-lag circuit was revised and preliminary tests on an early design of the circuit were conducted (auth)

44 (N-67-14925) FABRICATION AND TEST OF A FLUERIC POSITION SERVO. Progress Report, December 10, 1965-June 10, 1966. Erwin, L. R. (Bendix Corp., Southfield, Mich. Research Labs. Div.). June 10, 1966. Contract NAS3-6201. 31p. (NASA-CR-72129; BRLD-3512). CFSTI \$3.00 cy, \$0.65 mn.

A program to develop a pneumatic control drum actuator for a nuclear rocket engine in which the electronics have been replaced by flueric devices is reported. The detailed drawings for the position error detector unit and power control valve were released. Many purchased items have been received and a number of machined parts have been completed. Improvements were made on the flueric vortex pressure amplifiers. A breadboard lead-lag circuit was built and tested (auth)

California University, Berkeley

45 PROMPT-NEUTRON KINETICS OF A SPHERICAL CAVITY REACTOR. Podney, Walter N.; Smith, Harold P. Jr.; Oppenheim, A. K. (Univ. of California, Berkeley). Trans. Amer. Nucl. Soc., 9: 329-30 (Oct.-Nov. 1966)

California University, Livermore

46 AEROSPACE NUCLEAR PROPULSION TECHNOLOGY. Rothman, A. J. (Univ. of California, Livermore). pp 306-37 of Ceramics for Advanced Technologies. J. E. Hove; W. C. Riley (eds.). New York, John Wiley and Sons, Inc., 1965.

Nuclear reactors for aerospace propulsion systems are discussed. Both atmospheric nuclear propulsion and space nuclear propulsion are considered. The Aircraft Nuclear Propulsion and Pluto Projects are reviewed. Nuclear rockets are discussed. The solid-core nuclear heat exchanger (Project Rover) is considered in detail. (45 references) (F J H)

California University, Los Angeles

47 (UCLA-12-615) ENVIRONMENTAL CONTAMINATION FROM A NUCLEAR REACTOR AT THE NEVADA TEST SITE. Mork, Harold M.; Berta, Firmin J. (California Univ., Los Angeles. Lab. of Nuclear Medicine and Radiation Biology). Dec. 1966. Contract AT(04-1)-Gen-12. 22p. Dep. mn. CFSTI \$3.00 cy, \$0.65 mn.

After the test of the Kiwi-A reactor on July 1, 1959, the environmental contamination from the effluent was assessed. The fallout pattern was very narrow and extended on an approximate bearing of 350 degrees from the test cell. The maximum level of contamination ($16.2 \mu\text{Ci}/\text{ft}^2$ at H + 12 hrs) was measured at approximately 1.5 miles. The total activity associated with the smaller size fractions increased significantly, and there was a corresponding decrease in the activity of the larger size fractions with increase in distance from the test cell. The β radiation decay slopes deviated appreciably more from the $T^{-1.2}$ decay expression than previously observed slopes of fallout materials collected from weapons test activities. This variability indicated fractionation. The distribution of radionuclides was extremely variable at the several stations. The ^{140}Ba , ^{98}Mo , ^{103}Ru and ^{95}Zr - ^{95}Nb nuclides were detected at all stations. ^{141}Ce , ^{144}Ce and ^{106}Ru were generally present only at the closer stations, and ^{131}I , ^{91}Y and ^{137}Cs were represented only at the more distant locations. No levels of airborne fission product activity above normal background were detected at locations sampled 4 to 8 miles NE of the test cell. The less than 44 micron size fraction was slightly more soluble in

water and somewhat less soluble in 0.1 N HCl than the greater than 44 micron size fraction. The solubilities ranged from less than 1 to about 5 percent for water, and from about 8 to 24 percent for dilute acid. The levels of radioactivity observed after the Kiwi-A test were much less than those observed following weapons tests, however, the data suggested that a larger percentage of the radioactive debris from Kiwi-A than from weapons tests was available to the biological indicators, the native rodents and jack-rabbits (auth)

Catholic University of America, Washington, D. C.

48 (N-66-37315) A FUNDAMENTAL AND FEASIBILITY STUDY OF RING-VORTEX GASEOUS-CORE CAVITY REACTOR. Semianual Report No. 5, February 1-July 31, 1966. Chang, C. C. (Catholic Univ. of America, Washington, D. C.). Aug. 1, 1966. 19p. (NASA-CR-78048). CFSTI \$3.00 cy, \$0.65 mn.

The progress made in understanding the flow pattern in three types of reactor models is summarized. The models studied were the cylindrical geometry, toroidal geometry, and a two dimensional improvement on the Lewis Coaxial Core Reactor. It was found that the square step end walls of equal diameters are definitely promising in reducing secondary flow loss in the cylindrical model. The great advantage of toroidal geometry is the fluid vortex ring which has no open ends, therefore, the secondary flow loss can be eliminated. It is stated that further study is required on the two dimensional model. Abstracts of papers on radiative transfer for parallel streams of radiating gases, mass transfer between two parallel streams, and the stability of Helmholtz flow are also included (STAR)

Columbia University, New York

49 THE CRITICAL MASS OF CAVITY REACTORS WITH GASEOUS FISSIONABLE MASS FOR ROCKET ENGINES. Tumm, Guenter W. (Columbia Univ., New York). Raumfahrtforschung, 9: 105-11 (July-Sept. 1965). (In German).

The known nuclear physical problems in connection with the critical mass of the cavity reactor with gaseous fissionable substance are summarized with special consideration of the application to rocket engines. Some general conclusions are derived from the theoretical and experimental results. Special emphasis is given to the question of minimal critical mass considering the effects of interior and exterior fuel compression and fuel temperature. It is shown that the vortex flow-type requires a smaller critical mass than the coaxial flow-type under comparable conditions. (auth)

Douglas Aircraft Co., Inc., Santa Monica, Calif. Missiles and Space Division

50 (N-66-15495) AN ACOUSTICAL STUDY OF THE KIWI B NUCLEAR ROCKET. Manhart, J. Kenneth; Ailman, C. M.; Lane, S. R.; Marsh, A. H. (Douglas Aircraft Co., Inc., Santa Monica, Calif. Missile and Space Systems Div.). Jan. 1966. Contract NASw-596. 122p. (NASA-CR-370). CFSTI \$4.00 cy, \$1.00 mn.

Sound pressures generated by the exhaust of the KIWI B nuclear rocket engine were measured, and the data were analyzed. The characteristics of the radiated sound field that were identified include the: distribution of sound pressures with frequency; distribution of radiated sound power with frequency and total radiated sound power; directivity characteristics; conversion efficiency of exhaust mechanical stream power to sound power; space-time correlation of sound pressures in the near field; and probability distribution of instantaneous peak pressures. These characteristics were related to the flow parameters of the KIWI B exhaust and, where relevant, to acoustical data and flow parameters of chemical rocket engines. A method of normalizing the sound power spectra is introduced because the conventional methods did not satisfactorily relate the acoustical data from the KIWI B and chemical rocket engines. On the basis of two data sets from power runs of the KIWI B reactor, the acoustical conversion efficiency of the KIWI B exhaust is shown to be lower than for chemical rockets. In the near-field, the distribution of instantaneous peak pressures was found to be approximately Gaussian. In addition, the re-

sponse of simple structures to the KIWI B sound field was studied. Comparisons of measured and analytically derived response were made (STAR)

51 DYNAMICS OF CLUSTERED NUCLEAR ENGINES. Woyski, Jan. S. (Douglas Aircraft Co., Santa Monica, Calif.). IEEE (Inst. Elec. Electron. Eng.), Trans. Nucl. Sci., NS-13: No. 1, 676-84 (Feb. 1966).

A method of evaluating reactivity coupling between clustered rocket reactors was developed, and an analog model of a clustered nuclear propulsion system was used for the simulation of the complete operating cycle of such a system (D C W)

52 DYNAMIC PERFORMANCE OF CLUSTERED NUCLEAR ENGINES. Woyski, Jan S. (Douglas Aircraft Co., Inc., Santa Monica, Calif.). Trans. Amer. Nucl. Soc., 8: 555-7 (Nov. 1965).

53 FUELS FOR GASEOUS-CORE NUCLEAR ROCKETS. Holl, R. J.; Plunkett, T. F. (Douglas Aircraft Co., Inc., Santa Monica, Calif.). Trans. Amer. Nucl. Soc., 8: 609-10 (Nov. 1965).

54 NUCLEAR ANALYSIS OF GASEOUS-CORE NUCLEAR ROCKETS. Plunkett, Thomas F. (Douglas Aircraft Co., Inc., Huntington Beach, Calif.). Nucl. Appl., 3: 178-86 (Mar. 1967).

A nuclear analysis of a gaseous-core nuclear rocket engine is presented in which the spatial effects of the cavity liner material, coolant tubes, and structural components, as well as neutron streaming out of propellant inlet and outlet (nozzle) passages are considered. Calculational methods were evaluated, and multigroup diffusion theory was selected. Two-dimensional diffusion and transport calculations are compared for finite cylindrical cavity reactors having both central and annular nozzle exhausts. A parameter study was made of fuel and reflector materials, core and reflector dimensions, and temperature effects. It was found that extremely high fuel loadings are required for a propulsion reactor, substantial preheating of the reflector is required for startup, and ^{235}U has significant advantages over ^{238}U and ^{239}Pu as fuel in gaseous-core nuclear rockets (J R D)

55 SPACE-DEPENDENT DYNAMICS OF NUCLEAR PROPULSION ENGINES. Woyski, Jan S. (Douglas Aircraft Co., Inc., Santa Monica, Calif.). Trans. Amer. Nucl. Soc., 10: 11-12 (June 1967).

From 13th Annual Meeting of the American Nuclear Society, San Diego, Calif., June 11-15, 1967. See CONF-670602.

56 A TRANSPIRATION-COOLED NOZZLE AS APPLIED TO A GAS-CORE NUCLEAR PROPULSION SYSTEM. Kramer, E. L.; Gronich, S. (Douglas Aircraft Co., Inc., Santa Monica, Calif.). J. Spacecraft Rockets, 2: 345-53 (May-June 1965).

The use of mass injection through a porous wall as a cooling technique for axisymmetric nozzles is investigated. The effect of homogeneous mass injection on the heat transfer in a turbulent, compressible boundary layer is analyzed, using an integral-momentum approach. Approximate formulations of the gaseous thermal radiative and recombination energy contributions are included in the analysis. Coolant requirements are determined for a conical nozzle associated with a 10^6 lb-thrust gas-core system operating at a 300-atm chamber pressure. Hydrogen is assumed to be used for the propellant and coolant. Chamber temperatures range from 7500 to 20,000°R, and wall temperatures range from 2000 to 3000°R. The degradation of specific impulse, which is a result of expelling the coolant at a lower total temperature than that in the chamber, is found to be as high as 9% at 20,000°R for a wall temperature of 2000°R. (auth)

**Edgerton, Germeshausen, and Grier, Inc.,
Las Vegas, Nevada**

57 (EGG-1183-1054) TEST CELL A CONTROL SYSTEMS. Report No. L-660. Budge, Ezra (Edgerton, Germeshausen, and Grier, Inc., Las Vegas, Nev.). June 1, 1964. Contract AT(29-1)-1183. 219p. Dep. mn. CFSTI \$6.00 cy, \$1.25 mn.

An installation and operation manual is presented for the Project Rover Test Cell A controls system instrumentation. Descriptions and diagrams are included for major systems, subsystems, and shared or common equipment (H D R)

58 (EGG-1183-1244) PHOTO-OPTICAL INSTRUMENTATION AT THE NUCLEAR ROCKET DEVELOPMENT STATION. Lockwood, Harold E. (Edgerton, Germeshausen and Grier, Inc., Las Vegas, Nev.) [nd]. Contract AT(29-1)-1183. 18p. (CONF-660804-1) ORAU From Society of Photo-optical Instrumentation Engineers, 11th Annual Symposium, St. Louis, Mo

Prolonged and frequently interrupted tests, low frequency vibrations, and extreme environments impose severe requirements on photographic techniques and equipment design. Photographic objectives fall into two categories, Studies of fuel lines for leaks, and studies of the plane for symmetry and the existence of foreign material. Infrared and color film are the two principal photosensitive materials used in these studies. Equipment and station design criteria must provide for extended time coverage and remote operation of the cameras, protection of the film from extreme environments, particularly radiation, and the elimination of vibration (R C K)

Florida University, Gainesville

59 MODEL REFERENCE ADAPTIVE CONTROL OF A NUCLEAR ROCKET ENGINE. Humphries, Jack Thomas. Gainesville, Fla., Univ. of Florida, 1966. 134p.

Thesis.
Parameter adjustment model reference adaptive control of a nuclear rocket engine is investigated. The engine considered is similar to the solid-core 25,000 megawatt, million pound thrust model developed by Smith and Stenning. Proportional control gain for the control poison, i.e., rods or drums, is the parameter adaptively adjusted, and maximum core surface temperature is the adaptively controlled variable. Acceptable engine performance is achieved by using a second-order model with one finite zero. Engine response to step commands is particularly sensitive to change in the system's pressure time constant. With constant-parameter control, doubling this time constant results in doubling the system's transition time from an idling condition to full power. Adaptive control for the same condition achieves a transition time within 20 per cent of the desired, or "normal," response. Estimates of propellant savings with adaptive control are given, and dynamic stability of the system is discussed (Diss Abstr.)

**General Dynamics Corp., San Diego, Calif.
General Atomic Division**

60 (GA-5846(Rev.)) TUNGSTEN NUCLEAR ROCKET CRITICAL FACILITY: DESCRIPTION AND HAZARDS ANALYSIS. (General Dynamics Corp., San Diego, Calif. General Atomic Div.). Feb. 18, 1965. 179p. Dep. mn. CFSTI \$3.00 cy, \$0.65 mn.

An outline of the experimental program to be conducted at the facility is presented in which it is noted that no unusual or exceptionally hazardous experiments are planned. The core arrangement is such that addition or removal of single fuel elements does not involve inherently large reactivity changes. The same may be said of the poison inventory used to hold down excess reactivity. Descriptions are included concerning the facilities and the site. Safety aspects of the assembly are outlined and information is included on nuclear calculations for the facility, facility organization and procedures, and analyses of postulated accidents (J R D)

61 (GA-6807) PRECRITICAL CALCULATIONS FOR THE 3.0 IN. PITCH, BERYLLIUM REFLECTED, TWMR CRITICAL ASSEMBLY. Peak, J. C.; Lovallo, J. M. (General Atomic, San Diego, Calif. John Jay Hopkins Lab. for Pure and Applied Science). Nov. 8, 1965. Contract SNPC-27. 18p. (NASA-CR-54786).

In order to determine the feasibility of an isotopically enriched tungsten, water moderated reactor for use in a nuclear rocket, a critical assembly was fabricated and the necessary precritical neutronic calculations were made. The critical loadings are discussed and the precritical calculations for the 3.0 in pitch core with beryllium reflectors are summarized. (M O.W.)

62 (GA-6890) TUNGSTEN NUCLEAR ROCKET. PHASE I, FINAL REPORT. PART I. Bardes, R. G.; Cohen, S. C.; Friesenhahn, S. J.; Gillette, E. M.; Haddad, E.; Joanou, G. D.; Jupiter, C.; Moore, R. A.; Peak, J. C.; Trimble, G. D. (General Dynamics Corp., San Diego, Calif. General Atomic Div.). Apr. 22, 1966. Contract SNPC-27. 390p. (NASA-CR-54909).

The critical experiments and nuclear analysis performed at General Atomic in support of the Tungsten Water-Moderated Nuclear Rocket Reactor being developed by NASA-Lewis Research Center are described. Descriptions of the critical facility and the critical assemblies are given. Experimental measurements are presented and compared with analytical results. Analytical methods are reviewed and some critical experiments previously performed at the NASA-Lewis Research Center are analyzed. Three different core configurations of 121 fuel elements were assembled, two different pitches and both water and beryllium reflectors were used. Excess reactivity was held down by a cadmium nitrate solution contained in 204 poison tubes throughout the core. The fuel element consisted of an assembly of enriched uranium-aluminum alloy, depleted uranium, tungsten foil, and structural aluminum. Experimental results include the excess reactivity available in the cores, the worth of poison tubes and fuel element components at various locations, the temperature coefficient of the cores, flux and power distributions in a cell and throughout the core, neutron and gamma ray dose rate distributions throughout the core, pulsed neutron measurements, and reactivity comparisons using a special fuel section of enriched tungsten. Nuclear analysis of the assemblies required careful treatment of the extreme heterogeneities of the core. A detailed analysis which accounts for the two-dimensional cell structure, resonance overlap, and two-region resonance effects gave good agreement between calculations and the experimental results. (auth)

63 (GA-6942) GAMMA AND NEUTRON DOSE MEASUREMENTS FOR A THERMAL TUNGSTEN NUCLEAR ROCKET CRITICAL EXPERIMENT. Houghton, G.; Jupiter, C.; Trimble, G. (General Dynamics Corp., San Diego, Calif. General Atomic Div.). [1966]. Contract SNPC-27. 44p. (NASA-CR-72081).

Radial and axial dose distributions in Core III were measured by inserting thimble ionization chambers in the hollow spine of the fuel elements and poison tubes. The dosimeters were of two types, one sensitive mainly to energy deposition from fast neutrons and one sensitive primarily to gamma radiation. A time history of gamma intensity in the core was recorded. (J.R.D.)

64 (GA-7190) TUNGSTEN NUCLEAR ROCKET. PHASE II, FINAL REPORT. PART I. Bardes, R. G.; Bohren, C. F.; Cohen, S. C.; Peak, J. C. (General Dynamics Corp., San Diego, Calif. General Atomic Div.). June 15, 1966. Contract SNPC-27. 93p. (NASA-CR-54986).

Further critical experiments and nuclear analyses which were performed as part of a feasibility study of the Tungsten Water-Moderated Nuclear Rocket Reactor are described. A description of the critical facility and the critical assemblies is given. Two different core configurations were assembled; each core contained 121 fuel elements on a 3.0-in. pitch. The cores were water-moderated and surrounded by a beryllium reflector. Excess reactivity was held down by a $\text{Cd}(\text{NO}_3)_2$ solution contained in 204 poison tubes throughout the core. The fuel element consisted of an assembly of enriched U-Al alloy, depleted U, W foil, and structural Al. Additional W was added to each of the two cores for power zoning. The purpose of the zoning was to flatten the radial power and tailor the axial power profile. A radially zoned core was first constructed by the addition of W foils to fuel elements in a central core region, a fully zoned core was then constructed by adding W to an axial region of each fuel element of the radially zoned core. Experimental results include the excess reactivity available in the cores, the worth of poison tubes of different Cd concentration at various radial locations, the isothermal temperature coefficient of the assemblies, power distributions throughout the cores, and pulsed neutron measurements. The experimental results are compared with analysis. Nuclear analysis of the assemblies required careful treatment of the heterogeneous nature of the core. Detailed analyses which accounted for the two-dimensional cell structure, resonance overlap, and two-region resonance effects were compared with experimental results; good agreement was found for both water- and Be-reflected assemblies, zoned and unzoned assemblies, and assemblies with and without Cd poison. (auth)

65 EXPERIMENTAL AND ANALYTICAL RESULTS ON THE TUNGSTEN WATER-MODERATED NUCLEAR ROCKET CRITICAL ASSEMBLY. Bardes, R. G.; Bohren, C. F.; Cohen, S. C.; Gillette, E. M.; Livallo, J. M.; Moore, R. A.; Peak, R. A. (General Atomics, San Diego). Trans. Amer. Nucl. Soc., 9: 152-3 (June 1966).

66 ISOTHERMAL TEMPERATURE COEFFICIENT OF THE TUNGSTEN WATER-MODERATED ROCKET CRITICAL ASSEMBLY. Cohen, S. C.; Bardes, R. G.; Peak, J. C. (General Atomic, San Diego). Trans. Amer. Nucl. Soc., 9: 188-9 (June 1966).

67 TUNGSTEN WATER-MODERATED ROCKET CRITICAL ASSEMBLY, ANALYTICAL METHOD AND EXPERIMENTAL RESULTS. Peak, J. C.; Bardes, R. G. (General Atomic Div., General Dynamics Corp., San Diego, Calif.). Trans. Amer. Nucl. Soc., 8: 558 (Nov. 1965).

General Electric Co., Cincinnati

68 NUCLEAR HEATING CALCULATIONS IN A FAST-SPECTRUM REFRACTORY-METAL REACTOR ASSEMBLY. Edwards, W. E.; MacDonald, J. E.; Robertson, C. S. Jr. (General Electric Co., Cincinnati). Trans. Amer. Nucl. Soc., 9: 154 (June 1966).

General Electric Co., Idaho Falls, Ida. Nuclear Materials and Propulsion Dept.

69 (GEMP-402) NASA CAVITY REACTOR CRITICAL EXPERIMENT FINAL SAFETY ANALYSIS REPORT. (General Electric Co., Idaho Falls, Idaho. Nuclear Materials and Propulsion Operation) Jan. 12, 1966. Contract AT(40-1)-2847. 132p. Dep. CFSTI.

A description and safety analysis of a reflector moderated cavity reactor critical experiment to be operated at the Low Power Test Facility at the National Reactor Testing Station is given. The experimental core assembly will be mounted upon the split-table structure formerly used for the HOTCE critical experiment at this same facility. The proposed cavity reactor experiment will use the nuclear instrumentation and control system from the 630A Maritime Nuclear Steam Generator Critical Experiment, recently concluded, and also will be operated in the same test cell, by the same personnel and in accordance with essentially the same operating procedures and control limits as this latter experiment. Thus, although the nuclear core and reflector moderator are new, all other facilities, systems and procedures involved in the operation of the experiment are previously tested and proven. Potential nuclear accidents and radiological hazards are analyzed and found to be no more probable and considerably less severe than those of other experiments conducted at the LPT Facility. It is concluded that the conduct of this experiment will not create undue hazards to humans, either on or off-site. (auth)

General Electric Co., Philadelphia

70 APPLICATION OF NUCLEAR ELECTRIC PROPULSION TO MANNED MARS MISSIONS. Brown, Harold; Coates, Gordon L. (General Electric Co., Philadelphia). New York, American Inst. of Aeronautics and Astronautics, 1965, Preprint No. AIAA 65-414, 30p., \$1.00. (CONF-650711-51). ORINS.

From AIAA 2nd Annual Meeting and Technical Demonstration, San Francisco.

A manned Mars mission is used as an example for a study of the feasibility of manned interplanetary flight using an optimum combination of nuclear rocket and nuclear electric propulsion. Basic data are presented and analytical tools are developed for optimizing the design of the interplanetary vehicle and its trajectory. A particular mission profile, a particular set of powerplant propulsion and payload characteristics, and a resultant overall vehicle design concept are considered. The effects of variations in the assumed mission profile and in the vehicle subsystem characteristics are discussed. (A.G.W.)

Harvard School of Public Health, Boston, Mass.

71 (NYO-841-3(Rev.)) PROPOSED GAS AND AIR CLEANING SYSTEMS FOR ROVER ENGINE TEST STANDS (WITH SPECIAL REFERENCE TO FLOATING ROOF CONTAINMENT VESSELS). First, Melvin W.; Silverman, Leslie; Pender, Daniel; Dawson, Stanley (Harvard School of Public Health, Boston, Mass.). Nov. 1964. Revised Oct. 1965. Contract AT(30-1)-841. 65p. Dep. mn; CFSTI \$3.00 cy, \$0.75 mn.

Decontamination systems for rocket engine exhaust gases are discussed. Requirements for the gas cleaning systems are discussed. The technical features and economics of gas holding systems, on-stream gas cleaners, and confinement systems of underground tunnels are discussed. (M.O.W.)

Jet Propulsion Laboratory, Pasadena, Calif.

72 (N-67-19877) FLUID SYSTEMS DESIGN CONCEPT FOR A LARGE GAS-COOLED FISSION-ELECTRIC CELL REACTOR SPACE POWER PLANT. Moksli, D. J. (Jet Propulsion Lab., Pasadena, Calif.), Feb. 1, 1967. Contract NAS7-100. 49p. (NASA-CR-82939; JPL-TM-33-283). CFSTI.

The possibility of using a gas to transport waste heat from a large fission-electric cell reactor directly to a radiator is examined in order to obtain an estimate of (1) the pumping power that would be required for such a system; (2) the size and weight of the reactor, radiator and other major components, and (3) temperature distributions in the core and other parts of the system. Also, a separate coolant circuit is assumed for removing heat energy from this portion of the core and converting it to electrical power for pumping and auxiliary power by means of a Rankine cycle. The sizes and weights of the major components of the auxiliary power system are also estimated. An overall specific weight of about 6.9 to 13.0 lb/kW(e), not including shields, is obtained depending on the conversion efficiency: the higher weight corresponds to 5% conversion efficiency; the lower, to 10%. As might be expected, the radiator is found to be the largest and heaviest single component. However, the advantage in being able to radiate at a higher temperature is found to result in a potential reduction in radiator area of from 50 to 80% (depending on efficiency) as compared with that required for a comparable plant operating on a thermodynamic power-conversion cycle (auth)

Kansas State University, Manhattan

73 ANALYSIS OF TRANSIENT TEMPERATURES IN GAMMA-HEATED MATERIALS. Rumpf, N. K.; Mingle, J. O. (Kansas State Univ., Manhattan) J. Spacecraft Rockets, 4 1195-9 (Sept. 1967).

The heating of a slab by a plane beam of gamma radiation is analyzed to determine the resultant transient, spatial temperature distribution. When exposed to the 9.5×10^4 Btu/hr-ft² of radiation expected near unshielded high-power nuclear rocket reactors steel in thicknesses ≈ 0.25 in. would remain intact, but aluminum would melt in a few hours. Boundary conditions were an insulated face near the source and gray body thermal radiation to 500 R on the far surface. Another mathematical model representing the auxiliary cooling of structural rocket materials by the use of bleed gas, was employed by assuming that the previous slab is split into two parts with convective cooling in the cut. This analysis showed that the temperatures would be significantly reduced (auth)

Kernforschungsanlage, Juelich, Germany

74 THORIUM HIGH TEMPERATURE REACTOR PROJECT. Jelinek-Fink, P. (Kernforschungsanlage, Juelich, Ger.), Rausch, W.; Schafstall, H. G.; Schulten, R.; Valette, L. J. Brit. Nucl. Energy Soc., 5: 383-95 (July 1966).

An account is given of the work performed by association for Th high-temperature reactor serving the general purpose of the advancement of high-temperature pebble bed reactors utilizing the Th-U cycle and the design of a prototype reactor representative of a full scale power plant. The main characteristics of the prototype reactor are presented. Information on special details such as fuel elements, core design, fuel element cycle, cooling

Lockheed Missiles and Space Division, Sunnyvale, Calif.

75 DESIGN OF A NUCLEAR PROPULSION MODULE. McKereghan, Charles D. (Lockheed Missiles and Space Co., Sunnyvale, Calif.). New York, American Inst. of Aeronautics and Astronautics, 1966, Paper No. 66-548, 14p., \$1.50. (CONF-660608-10). ORAU.

From AIAA Second Propulsion Joint Specialist Conference.

A multipurpose nuclear stage, designed for a broad range of mission applications, is described. This stage, launched by an uprated Saturn V, can be used either directly in lunar support and deep-space missions or,

through orbital rendezvous and assembly, in manned interplanetary flight. Criteria for this modular vehicle and the resultant stage design are developed. The stage employs such features as meteoroid protection and super-insulation system required for the long-term storage in space associated with the interplanetary mission while providing sufficient performance gains to be attractive as a third-stage booster for the short-duration missions. The design of the propulsion module provides for an alternate configuration, a propellant module, that is used in a connecting mode to allow meeting the gross propellant requirements of the manned interplanetary mission vehicles. Designs of the necessary docking and assembly structures used in building up the overall interplanetary launch vehicle are presented as is the transfer stage used to deliver the modules from the phasing to the assembly orbit. The performance characteristics of the nuclear propulsion module are discussed and scaling laws are derived so that general mission analyses can be performed (auth)

76 (N-66-34793) DESIGN GUIDELINES FOR CIRCUITRY IN A NUCLEAR REACTOR-PROPELLED SPACECRAFT. Final Report. Westrom, John L. (Lockheed Missiles and Space Co., Huntsville, Ala.). July 1, 1966. Contract NAS8-11755. 114p. (NASA-CR-77419; LMSC/HREC-A782894). CFSTI.

Radiation resistant circuitry and power supplies are considered in a summary of the guidelines and design efforts for circuitry in a nuclear reactor-propelled spacecraft. Mention is made of the testing of building blocks and circuits, a 200-watt power supply utilizing a switching/summing waveform technique, and the regulator operation. Recommendations for future effort in radiation effects deal with topics such as damaging effects on semiconductors, selective sampling, radiation equivalency, variance of device parameters for transistors, and integrated circuitry. Development of a 400 Hz inverter and its computer mechanization are detailed, including the derivation of equations, block diagrams and circuit illustrations, and performance evaluation. A dc to dc converter is discussed, and an analysis of switching regulation includes details of the derivation of the various equations and the parameters for ideal switching frequency (auth)

77 (NP-16954) EVALUATION OF METHODS FOR COMPUTING NUCLEAR ROCKET RADIATION FIELDS. (Lockheed-Georgia Co., Marietta, Ga.). [1965]. Contract NAS8-9500. 119p. (ER-8236).

A critical evaluation of pertinent computer programs, emphasizing usefulness in future analysis and design of nuclear rocket systems, is presented. The computer programs discussed include point-kernel programs 14-0 (and 14-1), QAD-PS (and QAD-IV), and C-17, discrete ordinates programs DDK and DTK, and Monte Carlo programs 18-0, MCS and MCG, O5R, and COHORT (D C C)

78 IMPACT OF PROPELLANT HEATING ON NUCLEAR SPACECRAFT INSULATION AND PRESSURIZATION SYSTEMS DESIGN. Brogan, J. J. (Lockheed Missiles and Space Co., Sunnyvale, Calif.). J. Spacecraft Rockets, 3 932-4 (June 1966).

Liquid hydrogen propellant on a nuclear stage is exposed to space and nuclear heating. The combined and separate effects of these heating sources on propellant tank insulation and pressurization system design requirements are described (B G D)

Los Alamos Scientific Laboratory, New Mexico

79 (CONF-650407, pp 537-56) AIRBORNE RADIO-ACTIVITY AND CONTAMINATION PATTERNS FROM A TRANSIENT TEST OF A NUCLEAR ROCKET ENGINE. Fultyn, R. V. (Los Alamos Scientific Lab, Univ of California, N. Mex.)

The general experimental details of the Transient Nuclear Test (TNT) of a KIWI reactor and the specific details of documenting the resulting release of radioactivity are presented. The instrumented array gave 360° coverage from 100 to 1000 ft of the test point and 90° coverage out to approximately 50 miles. Air sampling instrumentation consisted of high volume air samplers, cycling samplers and Cascade impactors. Resin coated trays, film badges, and dose rate detectors were placed at stations within the array. Concentrations of airborne radioactivity resulting from the excursion are reported for distances of 4000 ft to 50 miles. Gaseous and particulate activity are reported

separately. The empirical data are compared to predictions made using the diffusion theories of Sutton and Pasquill with actual weather conditions as experienced used as parameters. A comparison is also made of the collected data and pre-event predictions, which used assumed weather conditions as parameters. Close-in site contamination resulting from reactor fragments too large to be classified as aerosols is described, and contamination from fallout is reported for distances of 4000 ft to 50 miles. (auth)

80 (CONF-650407, pp 557-65) THE CHARACTER OF THE EFFLUENT MATERIAL FROM A TRANSIENT TEST OF A NUCLEAR ROCKET ENGINE Henderson, R. W. (Los Alamos Scientific Lab., Univ. of California, N. Mex.)

The nature of the operation largely precludes the use of "wet chemistry," and fission product activities are determined from gross beta and gamma decay and gamma pulse-height analysis. With the data thus generated, the differences in the effluent of fission product material found and that predicted by theoretical calculations are demonstrated. The sampling array extending to 50 miles allows for the study of the behavior of the material in the atmosphere. Differences in the composition of the effluent cloud between 4000 ft and 50 miles are noted. Changes in the composition of the various fractions are due to chemical or elemental states at various times of collections, removal up-wind from the sampling point, and atmospheric dwell time. The iodine behavior is very complex in this system due to the collection of particulate precursors at close-in stations and the sorption of elemental iodine on nonactive airborne particulates at the far-removed stations. Whenever possible differentiation of the activation activity from fission product activity is accomplished. Results of fallout activity measurements are presented and compared with the airborne activity measured at the various sampling stations. (auth)

81 (LA-3367) THE BEHAVIOR OF COATED PARTICLES IN A LARGE NUCLEAR TRANSIENT (KIWI TNT). Geer, W. U.; Hoffman, C. G.; Kerrisk, J. F. (Los Alamos Scientific Lab., Univ. of California, N. Mex.). Sept. 1, 1965. Contract W-7405-eng-36. 78p. Dep. mn. CFSTI \$3.00 cy, \$0.75 mn.

Capsules containing extruded graphite fuel samples, loaded with 19 different types of coated particles, were exposed to the neutron pulse generated by the Kiwi Transient Nuclear Test (Kiwi TNT). The effects of flux, particle core material (UC_2 and UO_2), core diameter, coating thickness, and sample temperature on the graphite matrix damage and the coated particle damage were investigated. Visual, metallographic, and radiographic examination of the recovered samples produced the following conclusions: the total energy deposition was by far the most significant variable giving complete destruction of the samples at the highest energy depositions and little or no change at the lowest; particles with large core sizes showed more damage than those with small cores, neither coating thickness nor sample temperature significantly affected damage, and particles with UO_2 cores were more easily damaged than those with UC_2 cores. (auth)

82 (LA-3388) PIN TECHNIQUE FOR DISPLACEMENT MEASUREMENTS IN KIWI TNT. Washburn, Beverly; Hudson, C. E. (Los Alamos Scientific Lab., Univ. of California, N. Mex.). June 8, 1965. Contract W-7405-eng-36. 19p. Dep. mn. CFSTI \$1.00 cy, \$0.50 mn.

A pin technique used to measure relatively small, early outward displacements of the TNT reactor core and reflector cylinder components during the Kiwi Transient Nuclear Test is described. Considerations necessary to adapt this method to the environment of the reactor transient and the results are presented. An experiment to determine the times of closing of selected propellant passages using coaxial wires is also outlined. (auth)

83 (LA-3393) INTEGRAL GAMMA AND NEUTRON MEASUREMENTS ON THE PHOEBUS 1A-321 REACTOR. Worman, F. C. V.; Ahlquist, A. J. (Los Alamos Scientific Lab., Univ. of California, N. Mex.). Jan. 1966. Contract W-7405-eng-36. 52p. Dep. mn. CFSTI \$3.00 cy, \$0.50 mn.

Leakage radiation from Phoebus 1A-321 was evaluated. Integral measurements of gamma dose, neutron flux, and

neutron dose were made on all experimental plans that involved criticality. A total of 69 stations were implemented in three experimental plans. Gamma doses in air during a full-power run ranged from 1.15×10^6 rads at 60 feet to 2.50×10^1 rads at 2,100 feet. Thermal neutron fluxes declined from 96.5% of the total fast neutron flux at 60 feet to 28% at 3,000 feet. Included are additional gamma results obtained from film badges placed on arcs around the reactor with radii ranging from 1,000 to 128,000 feet. (auth)

84 (LA-3394) RADIATION MEASUREMENTS OF THE EFFLUENT FROM THE NRX A-2 AND NRX A-3 REACTORS. Henderson, R. W.; Larson, O. W. (Los Alamos Scientific Lab., Univ. of California, N. Mex.). Jan. 1966. Contract W-7405-eng-36. 51p. Dep. mn. CFSTI \$3.00 cy, \$0.50 mn.

Compilation of data resulting from the collection of samples of the effluent clouds from the NRX A-2 and A-3 reactors during full power operation is presented. Data are presented concerning the magnetic and isotopic composition of the airborne and ground deposition material. The environmental impact of these tests was calculated for hypothetical conditions of land use and occupancy and these data are included. A brief description of equipment and techniques is also given. (auth)

85 (LA-3395) RADIATION MEASUREMENTS OF THE EFFLUENT FROM THE KIWI TNT EXPERIMENT. Henderson, R. W.; Fultyn, R. V. (Los Alamos Scientific Lab., Univ. of California, N. Mex.). Oct. 1965. Contract W-7405-eng-36. 42p. Dep. mn. CFSTI \$2.00 cy, \$0.50 mn.

Included is a compilation of data resulting from the collection of samples of and direct measurements of the effluent cloud from the Kiwi Transient Nuclear Test experiment. Data are presented concerning the magnitude and isotopic composition of the airborne and ground deposited material at distances from 4,000 feet to 50 miles from the test point. Data from samples collected by cascade type impactors are given. Film dosimetry radiation measurements taken at the various stations are presented. A brief description of equipment and techniques used in the reduction is included. An appendix gives the true distance and azimuth of each sampling station with regard to the TNT test point. (auth)

86 (LA-3396) RADIATION MEASUREMENTS OF THE EFFLUENT FROM THE PHOEBUS 1A-321 REACTOR. Henderson, R. W.; Larson, O. W.; Fultyn, R. V. (Los Alamos Scientific Lab., Univ. of California, N. Mex.). Feb. 1966. Contract W-7405-eng-36. 59p. Dep. mn. CFSTI \$3.00 cy, \$0.75 mn.

Results are presented of documentation studies on the effluent from the full-power test of the Phoebus 1A-321 reactor. A description of procedures and equipment is given. An analysis of the environmental effects due to the passage and deposition of the released material is given, as well as deposition velocities measured at various locations. Results of the study of selected resin-coated trays by Los Alamos Scientific Laboratory Industrial Hygiene Group (H-5) are also presented. (auth)

87 (LA-3397) RADIATION MEASUREMENTS OF THE EFFLUENT FROM THE KIWI B4D-202 AND B4E-301 REACTORS. Henderson, R. W.; Fultyn, R. V. (Los Alamos Scientific Lab., Univ. of California, N. Mex.). Aug. 12, 1965. Contract W-7405-eng-36. 88p. Dep. mn. CFSTI \$3.00 cy, \$0.75 mn.

The results are presented of documentation studies on the effluent from the Kiwi B4D-202 and Kiwi B4E-301 reactors during full power tests. A description of procedures and equipment is also given. An analysis of the environmental effects due to the passage and deposition of released material is given as well as deposition velocities measured at various locations. (auth)

88 (LA-3428) ON POWER TRANSIENTS IN PROPULSION REACTORS INDUCED BY WATER INJECTION. Chezem, Curtis G. (Los Alamos Scientific Lab., Univ. of California, N. Mex.). Dec. 1965. Contract W-7405-eng-36. 52p. Dep. mn. CFSTI \$3.00 cy, \$0.50 mn.

The question of the magnitude of the nuclear transient resulting from the inflow of water into the core of a

NERVA-type reactor was considered. The core is assumed to be an array of small circular holes penetrating a thick solid. Initially water is allowed to enter the array, and the water-air interface is advanced through the channels in small steps during which steady-state conditions of flow, heat conduction and nuclear radiation heating are assumed to exist. Reactivity is added to the core as an empirical function of water penetration, and the core power time profile is traced. (auth)

89 (LA-3446) GAMMA DOSE RATE MEASUREMENTS—KIWI TRANSIENT NUCLEAR TEST. Sanders, Fred W. (Los Alamos Scientific Lab., Univ. of California, N. Mex.). Dec. 1965. Contract W-7405-eng-36. 30p. Dep. mn. CFSTI \$2.00 cy, \$0.50 mn.

Gamma-ray dose rates were measured after the destruction test of a prototype nuclear rocket reactor which was designated the Kiwi Transient Nuclear Test. Dose rates were measured around the test point out to 500 feet and in the downwind direction out to 8 000 feet. It was found that even as close as 100 feet from the test point dose rates were affected by wind direction. The passage of the effluent cloud was observed at 4,000 and 8,000 feet. Isodose rate contours were determined at several post-event times, and estimates of integrated dose to personnel making emergency entries were prepared. (auth)

90 (LA-3447) DOSE RATE MEASUREMENTS ON THE KIWI B-4D-202 AND KIWI B-4E-301 REACTORS. Sanders, F. W. (Los Alamos Scientific Lab., Univ. of California, N. Mex.). Jan. 1966. Contract W-7405-eng-36. 21p. Dep. mn. CFSTI \$1.00 cy, \$0.50 mn.

Gamma dose rates were measured at several distances from Kiwi reactors B-4D-202 and B-4E-301 during testing. Measurements performed were similar to those made on previous Kiwi reactors. Peak gamma dose rates of 3.17×10^4 and 3.22×10^4 R/min were measured at 60 feet from B-4D and B-4E, respectively. The eight Kiwi reactors tested have yielded rather uniform gamma dose rates per megawatt of reactor power, the average value is 35.1 R/min-Mw, measured at 60 feet. (auth)

91 (LA-3448) GAMMA DOSE RATE MEASUREMENTS ON THE PHOEBUS 1A-321 REACTOR. Ahlquist, A. J., Sanders, F. W. (Los Alamos Scientific Lab., Univ. of California, N. Mex.). Dec. 1965. Contract W-7405-eng-36. 19p. Dep. mn. CFSTI \$2.00 cy, \$0.50 mn.

Gamma-ray dose rate measurements were made on Experimental Plans 2, 3, and 4 of the Phoebus 1A-321 reactor testing series. Extrapolation of data from 180 feet gave a dose rate of 36.0 R/min-MW at the 60 foot station during the full power run (Experimental Plan 4). The average gamma-ray dose rate of the eight Kiwi reactors at the 60 foot station was 35.1 R/min-MW. Instrument difficulties necessitated using xylene (gamma-neutron sensitive) detectors as gamma detectors. Integral doses show that they give a reasonable approximation of gamma dose rates. (auth)

92 (LA-3470) FISSION COUPLES APPLIED TOWARD REACTOR DIAGNOSTICS AND SAFETY. Morrison, R. G., Stillman, D. B. (Los Alamos Scientific Lab., Univ. of California, N. Mex.). Jan. 15, 1966. Contract W-7405-eng-36. 31p. Dep. mn. CFSTI \$2.00 cy, \$0.50 mn.

A technique was developed for the Kiwi Transient Nuclear Test which used fissile material as a sensing element for reactor transient measurements and detailed fuel studies. This was done by welding very small thermocouple leads to the actual fuel material and forming an "intrinsic" junction. The response of this sensor has given accurate measurements of the reactor periods as short as 15 μ sec. A hypothesis is discussed that the heat produced by fission fragments in the fissile material can be monitored with sufficient accuracy to form a direct measurement of reactor power. (auth)

93 (LA-3494) LOS ALAMOS COUPLED REACTOR EXPERIENCE. Chezem, C. G., Hansen, G. H., Helmick, H. H., Seale, R. L. (Los Alamos Scientific Lab., N. Mex.). Mar. 1, 1966. Contract W-7405-eng-36. 52p. Dep. mn. CFSTI \$3.00 cy, \$0.65 mn.

The interaction among the cores in a cluster of nuclear rocket reactors and the resulting static and kinetic behavior of the array

has been studied analytically. Lumped-parameter models of two-core coupling have been analyzed by neutron pulsing and rod oscillation and their salient features verified at zero power by a variety of measurements on two Kiwi-type reactors operating in proximity. The Kiwi "free-space" coupling coefficients were determined experimentally to be 24.7, 11.9, and 3.3 cents at 6, 9, and 16 ft center-to-center separations. Perturbation of the fission distribution as a result of interaction at equal power was less than 5% at 6 ft. No neutronic instability was found either in the theoretical models or in the experimental behavior. Temperature dependence is introduced into the coupling model based on experimental evidence from the high-power, full-flow operation of a single Kiwi reactor. The temperature-dependent model is then extrapolated to predict the transfer function behavior of both Kiwi and Phoebus clusters under operating conditions. (auth)

94 (LA-3519) KIWI TRANSIENT NUCLEAR TEST DOSE RATE SURVEY. Lee, P. K.; Fultyn, R. V. (Los Alamos Scientific Lab., Univ. of California, N. Mex.). Mar. 1966. Contract W-7405-eng-36. 51p. Dep. mn. CFSTI \$3.00 cy, \$0.50 mn.

Following the KIWI TNT event, intensive, accurate dose rate surveys were taken of the contaminated areas surrounding the test point. The data collected during these surveys, and decay relations derived therefrom, are presented. (auth)

95 (LA-3583) RADIATION MEASUREMENTS OF THE EFFLUENT FROM THE NRX A-4 REACTOR. Larson, Oliver W.; Ahlquist, A. John; Henderson, Richard W. (Los Alamos Scientific Lab., N. Mex.). Aug. 1966. Contract W-7405-eng-36. 125p. Dep. mn. CFSTI \$3.00 cy, \$0.65 mn.

The results of documentation studies on the effluent from the NRX A-4 EP-III, EP-IV, and EP-IVA full-power reactor tests are presented. Sampling procedures and equipment are described, and an analysis of the environmental effects due to the passage and deposition of the released radioactive material is given. (auth)

96 (LA-3622) TEST CELL C SHIELDING STUDY. KIWI B4D-202. Ahlquist, A. John; Dummer, Jerome E. (Los Alamos Scientific Lab., N. Mex.). Nov. 1966. Contract W-7405-eng-36. 27p. Dep. mn. CFSTI \$3.00 cy, \$0.65 mn.

Gamma and neutron doses at 71 and 19 stations, respectively, in the Test Cell C complex at the Nuclear Rocket Development Station were measured during the full-power run of the Kiwi B4D-202 reactor to determine shielding effectiveness of the test cell structures. (auth)

97 (LA-DC-6751) COMPUTING METHODS FOR ROVER REACTORS. Mills, C. B. (Los Alamos Scientific Lab., Univ. of California, N. Mex.). [1964]. Contract W-7405-eng-36. 59p. Dep. mn. CFSTI \$3.00 cy, \$0.75 mn.

The numerical approximations to the diffusion and transport equations for neutron flux in a reactor are written as intervals in space and angle for each set of connected energy intervals. The conventional transport forms are also reviewed for anisotropic scattering cross sections and resonance integrals. Reducing an actual reactor experiment to a mathematically computable form requires the combination of theoretical and experimental approximations in ways specific to the experimental assembly. This procedure involves three steps: (1) homogenization and symmetrization of the geometrically coarse-grained assemblies, with changes in neutron cross section to effective values where appropriate, (2) weighting of moderator volume and reactor dimensions for equivalent neutron transport and slowing down, and (3) comparison of a systematic and simple experimental display to evaluate errors. The computing system was applied to a high-power reactor experiment and proved to be entirely adequate in the area of interest. Measurements of fission density as a function of space at high temperature corresponded well with the expected distribution. (M.O.W.)

98 (LA-DC-7244) NUCLEAR REACTOR CONTROL WITH STEPPING MOTOR ACTUATORS. Strait, Bobby G.; Lang, Robert M. (Los Alamos Scientific Lab., Univ. of California, N. Mex.). [1966]. Contract W-7405-eng-36. 29p. (CONF-660608-7). Dep. mn. CFSTI \$2.00 cy, \$0.50 mn.

From 2nd AIAA Propulsion Joint Specialist Conference, Colorado Springs.

A control rod actuator system capable of reproducing the position of rotary control rods to 0.01° was developed for

the Phoebus-2 Zepo critical assembly (a zero power neutron mockup for the Rover reactor, Phoebus-2) The heart of the actuator is an electric stepping motor whose output shaft rotates 1.8° for each input electrical pulse Each step is accurate to $\pm 5\%$ and the rotational error is non-cumulative Steps of 0.01° are obtained by means of a 180:1 gear reduction, combined with a spring load on the output shaft to eliminate backlash Control rod position information is obtained by simply counting algebraically the number of electrical pulses which step the motor The safety philosophy is based on limiting the pulse rate, which limits the rate of increase of reactivity In addition, a fail-safe scram system is provided in the form of an electrically-operated clutch, which decouples a control rod from its gear train and allows a spring to scram the rod The system also includes a power level control loop which uses either one or two control rods as the control elements The electronic controls for the stepping motors consist of highly reliable transistor circuits which operate in switching fashion, that is, the transistors are completely on or off (auth)

99 (LA-DC-7514) MEASUREMENT OF PRESSURE-TO-PRESSURE TRANSFER FUNCTIONS THROUGH THE PHOEBUS-1A NUCLEAR REACTOR. Johnson, James A. (Los Alamos Scientific Lab., Univ. of California, N. Mex.). [1965]. Contract W-7405-eng-36. 21p. (CONF-660206-3). ORAU.

From Symposium on Neutron Noise, Waves, and Pulse Propagation, Gainesville, Fla.

During the full power hold of the Phoebus-1A Nuclear Reactor test series, a pseudo-random noise signal was introduced into the turbo-pump flow demand and, with pre-emphasis, into the turbo-pump speed demand to cause pressure fluctuations in the reactor coolant system The purpose of this experiment was to obtain dynamic response measurements of coolant pressure from the nozzle inlet plenum to the core exit plenum The amplitude of the pressure perturbations in the nozzle inlet plenum was 17.5 psi peak-to-peak and 6.6 psi peak-to-peak in the core exit plenum The pressure-to-pressure transfer functions of the nozzle coolant tubes, the reflector, and the core were obtained over a limited range of frequencies during the same experiment The data were analyzed using the cross-correlation method The results were excellent and essentially in agreement with the predictions for the experiment The range of frequencies covered by the experiment is from 0.2 to 10 cps (auth)

100 (LA-DC-7636) PROPULSION REACTOR TEMPERATURE CONTROL WITH THE INTERNAL POWER LOOP ELIMINATED. Brown, E. A.; Balcomb, J. D. (Los Alamos Scientific Lab., Univ. of California, N. Mex.); Josephson, J.; Junker, D. W.; Mackey, L. (Westinghouse Electric Corp., Pittsburgh, Pa. Astronuclear Lab.). [1965]. Contract W-7405-eng-36. 11p. (CONF-660608-3). Dep. mn. CFSTI \$1.00 cy, \$0.50 mn.

From 2nd AIAA Propulsion Joint Specialist Conference, Colorado Springs.

Incremental changes of either temperature or the mass of hydrogen in Rover and NERVA reactors generate natural feedback reactivity which makes the reactor self-stabilizing An increase in reactivity generated by either rod position or flow rate increases will raise power This will increase core and gas temperature which decrease reactivity Thus the system will come to a new balance at slightly higher power and temperatures when the natural reactivity decrease just offsets the increase from rod position or flow rate changes At 1000 megawatts power and 70 lbs/sec flow rate, the static incremental gains from control rod position and flow rate to average core temperature are $68^\circ\text{R}/^\circ$ and $31^\circ\text{R}/\text{lbs/sec}$ respectively The natural reactivity loop also tends to cancel the nonlinear effects of the reactivity-to-power gain dependency on power level and the core heat exchanger bandwidth dependency on flow rate Advantage was taken of these core characteristics in developing a new temperature control system which does not have the internal power control loop common to earlier propulsion reactors The change has resulted in considerably improved temperature control system stability and reliability (auth)

101 (LA-DC-7637) COOLED HIGH-TEMPERATURE THERMOCOUPLES FOR PHOEBUS REACTORS.

Goodier, Benjamin G. (Los Alamos Scientific Lab., Univ. of California, N. Mex.). [1965]. Contract W-7405-eng-36. 17p. (CONF-660608-5). Dep. mn. CFSTI \$1.00 cy, \$0.50 mn.

From 2nd AIAA Propulsion Joint Specialist Conference, Colorado Springs.

Thermocouple measurements of high temperatures, around 5000°R, in the Project Rover reactors were quite unreliable Carbon attack upon the refractory metals and the degradation of the resistivity of the electrical insulators were the chief offenders Phoebus engine design dictates that a long portion of the thermocouple leads pass through the reactor core to the point of interest By cooling the thermocouple elements along this length except for a short distance at the tip, electrical shunting and chemical attack are minimized Cooling of these thermocouples is accomplished by thermally insulating this portion of the thermocouple lead from the surrounding graphite and flowing hydrogen around the lead then diverting this flow away from the sensing area This approach was effective in Phoebus-1A exit gas measurements and will be used for both exit gas temperatures and core material temperatures in Phoebus-1B (auth)

102 (LA-DC-7641) ON THE EFFECTS OF COOL-DOWN REQUIREMENTS UPON MISSION APPLICATIONS FOR NUCLEAR ROCKETS. Fenstermacher, Charles (Los Alamos Scientific Lab., Univ. of California, N. Mex.); Oakley, Donald T. (Public Health Service, Las Vegas, Nev.). [1965]. Contract W-7405-eng-36. 14p. (CONF-660608-4). Dep. mn. CFSTI \$1.00 cy, \$0.50 mn.

From 2nd AIAA Propulsion Joint Specialist Conference, Colorado Springs.

When considering mission applications for nuclear rockets, one encounters the problem of the delayed energy produced by fission product decay after the full power operation phase If restarts are not planned for the engine, the problem can be ignored because each engine is jettisoned at the end of its operation However, if restarts are considered, at least two aspects of the cooldown problem must be examined First, the program necessary for safe reactor cooldown and propellant requirements for this and second, the feasibility of producing useful thrust during this cooldown Studies were made of the cooldown requirements as a function of operating times for mission applications at the NERVA-2 power level and their effects on the specific impulse and vehicle weight These calculations include realistic limits upon exit gas temperatures imposed by reactor design considerations The effects upon I_{sp} were studied using as a parameter the fraction of cooldown propellant assumed to produce thrust The results indicate I_{sp} degradation of 2 to 15 seconds and vehicle weight increases of 6,000 to 40,000 lbs over the range considered (auth)

103 (LA-DC-7649) DESIGN AND ANALYSIS OF AN EMERGENCY COOLDOWN SYSTEM FOR NUCLEAR ROCKET REACTOR GROUND TESTS. Nutter, Murlin J.; Breisch, George; Fenstermacher, Charles (Los Alamos Scientific Lab., Univ. of California, N. Mex.). [nd]. Contract W-7405-eng-36. 22p. (CONF-660608-6). Dep. mn. CFSTI \$1.00 cy, \$0.50 mn.

From 2nd AIAA Propulsion Joint Specialist Conference, Colorado Springs.

A system is described which will automatically provide coolant to a nuclear rocket test reactor during the initial portion of an emergency shutdown The adiabatic expansion of the pressurizing gas in a variable volume automatically programs the flow of LH_2 from a high pressure dewar, through suitable valving, to cool the reactor safety when a system malfunction, facility failure, spurious signal or unpredicted reactor operation causes an emergency shutdown Calculations involving the solution to the system differential equations, indicate that an acceptable shutdown can be produced for emergency shutdown situations over the range of expected Phoebus I and II operating conditions (auth)

104 (LA-DC-7689) PROJECT ROVER LIQUID HYDROGEN SAFETY. A FIVE YEAR LOOK. Ehrenkranz, T. E. (Los Alamos Scientific Lab., Univ. of California, N. Mex.). [1965]. Contract W-7405-eng-36. 15p. (CONF-660605-2). Dep. mn. CFSTI \$1.00 cy, \$0.50 mn.

From Cryogenic Engineering Conference, Boulder, Colo. Large scale use of liquid hydrogen has been associated

with Project Rover at Jackass Flats, Nevada, since 1959. There were misadventures, these, together with the advice of specialists led to continuing improvements in procedures and equipment. Main components of the liquid hydrogen system are described, incidents and the lessons learned are related and the gradual refinement of safety devices and procedures are traced. It is felt today that standing operating procedures, control over incompatible operations, room inerting, remote control of high hydrogen flow rates and proven equipment reliability make the main contributions to carrying out large scale liquid hydrogen operations with confidence (auth)

105 (LA-DC-7703) ADVANCED CONCEPTS FOR NUCLEAR PROPULSION AND RELATED PROBLEMS IN HIGH TEMPERATURE CHEMISTRY. Bowman, Melvin G. (Los Alamos Scientific Lab., Univ. of California, N. Mex.) [nd]. Contract W-7405-eng-36 7p (CONF-660106-1) Dep. mn CFSTI \$1.00 cy, \$0.50 mn

From Meeting on Current and Future Problems in High Temperature Chemistry, Houston, Tex

Various concepts proposed for nuclear propulsion and related problems in high-temperature chemistry are discussed. These include rocket engines, heat exchanger reactors, use of nuclear reactors for production of electrical power, and chemical rocket engines (P C H)

106 (LA-DC-7781) REVIEW OF TRANSFER FUNCTION MEASUREMENTS IN THE NUCLEAR ROCKET PROGRAM USING NOISE TECHNIQUES. Wasserman, A. A.; Bodenschatz, C. A.; Steiner, G. H.; Honka, E. K.; James, L. R. (Westinghouse Electric Corp., Pittsburgh, Pa. Astronuclear Lab.); Balcomb, J. D.; Johnson, J. A.; Springer, T. E. (Los Alamos Scientific Lab., Univ. of California, N. Mex.). [1966]. Contract W-7405-eng-36. 18p. (CONF-660608-9). Dep. mn. CFSTI \$1.00 cy, \$0.50 mn.

107 (LA-DC-8174) DIGITAL COMPUTER SIMULATION OF FLUID FLOW AND HEAT TRANSFER IN NUCLEAR PROPULSION REACTORS. McClary, John A.; Murray, Suzanne T. (Los Alamos Scientific Lab., N. Mex.). [nd]. Contract W-7405-eng-36. 21p. (CONF-670706-1). Dep. CFSTI. From 3rd Propulsion Joint Specialist Conference, Washington, D. C.

A characteristic family of engineering problems is described by conduction, convection, and/or radiation from solid materials. Such problems are basic in designing and analyzing heat exchangers in general and nuclear reactors of the solid core heat exchangers in particular. A method of solution with general applications has evolved during the development of nuclear rocket propulsion reactors. The method provides accurate detailed calculations of fluid temperature, pressure, flow, and solid material temperature distributions in a variety of flow passage configurations and solid geometries with real state and transport properties of the materials. The method of solution has been programmed for digital computers (FORTRAN IV for IBM 7094 and CDC 6600) with the code name OPTION. A new version of the code was recently programmed and satisfies its objectives more completely than the previous version. The new code is described (auth)

108 (LA-DC-8516) SUMMARY OF COUPLED KIWI EXPERIENCE. Helmick, Herbert H.; Chezem, Curtis G. (Los Alamos Scientific Lab., N. Mex.). [nd]. Contract W-7405-eng-36. 8p. (CONF-670107-3) Dep. mn. CFSTI \$3.00 cy, \$0.65 mn.

From American Nuclear Society, Coupled Reactor Kinetics Conference, College Station, Tex.

The neutronic stability of a two-core cluster of nuclear rocket engines of the Kiwi and Phoebus I class was confirmed by measurements of transfer functions and pulsed neutron source behavior. Techniques for computing the coupling parameters and power perturbations were verified by static measurements on the coupled system (M L S)

109 (LA-DC-8716) STUDIES OF FORCED CONVECTION HEAT TRANSFER TO CRYOGENIC FLUIDS. Williamson, K. D. Jr.; Bartlett, J. R.; Thurston, R. S. (Los Alamos Scientific Lab., N. Mex.). [1967]. Contract W-7405-eng-36. 30p. (CONF-671103-3). Dep. CFSTI.

From 60th Annual Meeting of the American Institute of Chemical Engineers, New York.

Recent forced convection heat transfer studies for LH₂ and LN₂ have been directed at steady and oscillating flow, correla-

tion of data from many authors, and instrumentation problems. Data were obtained in pipes ranging in size from 1/4-in to 4 5-in ID. (auth)

110 (LA-DC-8725) CRYOGENIC RESEARCH AT THE LOS ALAMOS SCIENTIFIC LABORATORY. Hammel, E. F. (Los Alamos Scientific Lab., N. Mex.). [1967]. Contract W-7405-eng-36. 31p. (CONF-670409-2) Dep. CFSTI.

From International Cryogenic Engineering Conference, Kyoto, Japan

Facilities used in cryogenic research at the Los Alamos Scientific Laboratory for the development of high thrust nuclear propulsion systems for space exploration are discussed. The largest cryogenic test cell is described and cryogenic engineering items such as storage dewars, axial flow pumps capable of attaining 100 atm pressure, H₂O-H₂ heat exchangers, vacuum jacketed transfer lines and flow control systems are discussed. Problems of superconductivity and superfluidity are analyzed. Self-presurization studies, providing insight into the heat energy distribution in storage dewars are described (F S)

111 AUTOMATIC PHOTOGRAPHIC SYSTEM FOR RADIOACTIVE REACTOR FUEL ELEMENTS. Kee, R. W.; Perlee, R. E.; Rose, D. G. (Los Alamos Scientific Lab., N. Mex.) Trans. Amer. Nucl. Soc., 9 340-1 (Oct.-Nov. 1966)

112 AUTORADIOGRAPHY OF FUEL ELEMENTS OF THE KIWI REACTOR. AN EXPERIMENTAL NUCLEAR ROCKET ENGINE. Wagner, G. F.; Bahl, K. L.; Tenney, G. H. (Univ. of Calif., Los Alamos, N. Mex.). Mater. Evaluation, 23: 502-7 (Oct. 1965).

The final phase of evaluating the performance of an experimental nuclear rocket engine consists of the study of many components once the reactor has been disassembled. An important phase of this postmortem study is the fission density distribution in individual fuel elements. Data on the possible existence of abnormalities among fuel elements which are indicative of unusual conditions of neutron flux and/or core temperatures or faulty performance of individual elements are presented. An autoradiographic technique was developed and applied to this study. Special jigs and instruments were designed in order to implement the technique to highly radioactive elements using remote operations in hot cells. The instruments, selection of films, automated film density read-out, and comparison of the data with those obtained from a collimated NaI (Tl) scintillator system are described (auth)

113 FABRICATION AND PROPERTIES OF COPPER-BORON CARBIDE CONTROL MATERIAL FOR PHOEBUS II REACTOR. Sheinberg, H.; Keil, R. W. (Los Alamos Scientific Lab., N. Mex.). Trans. Amer. Nucl. Soc., 9. 11-12 (June 1966).

114 KIWI TEMPERATURE COEFFICIENT. Mills, C. B. (Los Alamos Scientific Lab., N. Mex.). Trans. Amer. Nucl. Soc., 8 552-3 (Nov. 1965).

115 MANIFOLD GASEOUS ROCKET REACTOR. Mills, Carroll B. (Los Alamos Scientific Lab., N. Mex.). Nucl. Appl., 3 397-8 (July 1967). (LA-DC-8702).

A discussion of the manifold gas-to-gas heat-transfer reactor is given. Critical ²³⁵U concentration and gas mass are calculated as a function of gas radius for the reactor core. The effective multiplication factor as a function of fuel radius in a cylindrical cavity is given. A comparison of critical ²³⁵U fuel concentration is given between core-moderated homogeneous reactors and reflector-moderated reactors (M L S)

116 PARTICLE-SIZE DISTRIBUTIONS FROM ROVER FUEL-ELEMENT FRAGMENTATION STUDIES. Campbell, E. E.; Ide, H. M.; Moss, W. D.; Reithel, R. J. (Los Alamos Scientific Lab., N. Mex.). Trans. Amer. Nucl. Soc., 8 566-7 (Nov. 1965).

117 PROSPECTS FOR ADVANCED HIGH-THRUST NUCLEAR PROPULSION. Cooper, Ralph S. Astronaut. Aeronaut., 4: 54-9 (Jan. 1966). (LA-DC-6961).

Basic technical factors and problem areas are described for concepts that offer the possibility of improved performance as nuclear propulsion systems. Concepts considered include fluidized beds, liquid-core rockets, gas-core schemes, and pulsed nuclear rockets. The fluidized-bed and liquid-core engines appear technically feasible al-

though very little work has been done on them. The gas-core concepts are definitely in the research stage. The open-pulse nuclear rocket has received considerable research effort, short of nuclear tests of ablation, and still appears technically feasible. It is concluded that no clear course is open at present. (30 references) (A G W)

118 SOME FEASIBILITY STUDIES OF THE NUCLEAR DESTRUCT CONCEPT FOR ROVER REACTOR DISPOSAL. King, L. D. P.; Mills, C. B. (Los Alamos Scientific Lab., N. Mex.). Trans. Amer. Nucl. Soc., 8 565-6 (Nov. 1965).

Massachusetts Institute of Technology, Cambridge

119 (N-65-11146) REACTIVITY CHANGES DURING STARTUP IN LARGE NUCLEAR ROCKETS [Thesis]. Little, Winston W., Jr. (Massachusetts Inst. of Tech., Cambridge). Aug. 1964. 161p. (NASA-CR-59533, MITNE-52). CFSTI \$5.00 cy, \$1.00 mn.

The material properties, such as core temperature, hydrogen density, etc., were computed as a function of time during startup for a specified power and flow-rate buildup. Using these time-dependent properties, the reactivity variations during startup were calculated using a diffusion theory model with 55 energy groups. The spatial dimensions were approximated by assuming $\nabla^2 \phi(E) = -B^2 \phi(E)$. It was found that large thermal nuclear rocket reactors ($C/U = 2500$) are much more sensitive to changes in hydrogen density and core temperature than small nuclear rockets ($C/U = 250$). The large reactivity coefficients present in thermal reactors cause both large ($\sim -\$13$) and rapid ($\sim -\$1/\text{sec}$) reactivity variations during the quick startups contemplated for nuclear rockets. This problem can be ameliorated to some degree by adding a nuclear poison to the core. However, any poison has the adverse side effect of decreasing the worth of an external control rod system by decreasing the leakage. An estimation of the worth of an external control rod system was obtained using a one-dimensional nucleonics model with three energy groups (auth)

Memphis State University, Tennessee

120 MHD SPECIES SEPARATION IN A GASEOUS NUCLEAR ROCKET USING A TIME VARYING TRAVELING WAVE ELECTROMAGNETIC FIELD. Rashad, A. R. M. (Memphis State Univ., Tenn.). New York, American Inst. of Aeronautics and Astronautics, 1966, Preprint No. 66-499, 11p., \$1.50. (CONF-660632-4). ORAU.

From American Inst. of Aeronautics and Astronautics, 4th Aerospace Sciences Meeting, Los Angeles, Calif.

The first part of a series of studies concerning a suggested method for the separation of the ^{235}U fuel from the H_2 propellant in a gaseous nuclear rocket is presented. The species are separated by magnetohydrodynamically spinning the plasma in a cylindrical vortex, using a time varying traveling wave electromagnetic field. The interaction of the plasma induced currents with the magnetic field, produces the azimuthal $\vec{J} \times \vec{B}$ force required to rotate the plasma and separate the ^{235}U fuel from the H_2 (auth)

National Aeronautics and Space Administration, Cleveland, Ohio. Lewis Research Center

121 (N-65-29479) APPLICATIONS OF LOW-POWER NUCLEAR ROCKETS. Rom, Frank E. (National Aeronautics and Space Administration, Cleveland, Ohio. Lewis Research Center). [1964]. 17p. (NASA-TM-X-52048). CFSTI \$1.00 cy, \$0.50 mn.

Large velocity increments necessary to achieve scientific missions of interest require the use of lightweight nuclear power plants since all chemical systems cannot accomplish many missions which the nuclear systems can. The velocity requirements of low-power missions are pointed out. The performance that would be attainable with

the use of these low-power missions on booster systems that are currently developed or being developed is discussed (STAR)

122 (N-66-35211) ANALYSIS OF THE TRANSIENT FLOW OF HYDROGEN IN HEATED PASSAGES IN THE LAMINAR-TURBULENT TRANSITION REGION. Leko, Robert W. (National Aeronautics and Space Administration, Cleveland, Ohio. Lewis Research Center). Sept. 1966. 24p. (NASA-TN-D-3629). CFSTI \$3.00 cy, \$0.65 mn.

A transient analysis was made of the flow characteristics in a single heated tube of circular cross section, and was made in association with phenomena occurring in the nuclear rocket reactor core. Twelve perturbations of heat flux into the tube wall, five perturbations in inlet pressure, and four perturbations of pressure drop were considered. The results are depicted in terms of the phase plane that generalizes the results and illustrates all flow behavior of the laminar instability condition. The external parameters considered, which influence the transient behavior of the system, were inlet pressure, outlet pressure, inlet enthalpy, and heat flux into the tube wall. Five kinds of transients were found. The first corresponds to an initial laminar flow rate on the steady-state curve which when perturbed goes to a turbulent equilibrium point. The second starts from the laminar flow rate on the steady-state curves and terminates at zero flow rate. A third begins from an operating point corresponding to a turbulent flow rate on the steady-state curve and proceeds to an equilibrium point at a higher turbulent flow rate. The fourth is initiated from a turbulent point on the steady-state curves and reaches a stable equilibrium point at a lower turbulent flow rate. The last begins at a turbulent steady-state point and terminates at zero flow. The "stability criterion" near equilibrium points is simply that the four external parameters give an operating point with a positive pressure drop as a function of flow rate slope on the characteristic curves. If this slope is negative or if there is no operating point, then the condition is unstable (auth)

123 (N-66-39615) ANALYSIS OF TOPPING AND BLEED TURBOPUMP UNITS FOR HYDROGEN-PROPELLED NUCLEAR ROCKETS. Evans, David G.; Crouse, James E. (National Aeronautics and Space Administration, Cleveland, Ohio. Lewis Research Center). June 1960. 45p. (NASA-TM-X-384). CFSTI \$3.00 cy, \$0.65 mn.

The turbopump units analyzed were a bleed, a hot-topping (full-flow turbine) and a cold-topping unit. The types of configuration required and their effect on rocket gross weight were investigated. The scope of the analysis did not include the effects of the turbopump configurations on the weights of associated components, such as the reactor (STAR)

124 (N-67-25841) CONTROLS ANALYSIS OF NUCLEAR ROCKET ENGINE AT POWER RANGE OPERATING CONDITIONS. Arpasi, Dale J.; Hart, Clint E. (National Aeronautics and Space Administration, Cleveland, Ohio. Lewis Research Center). May 1967. 67p. (NASA-TN-D-3978). CFSTI.

Techniques used to evaluate the dynamics of a nuclear rocket engine for control purposes are presented. A linear analysis, applied to transfer functions describing a NERVA-type engine at various operating conditions, was used to develop stable engine control in the power range of operation. The power range of operation is defined as that region of engine operation above 1 percent reactor power and 10-percent propellant weight flow. The effects of operating level and reactor period on the engine dynamics were considered in the analysis by investigating these dynamics at four engine operating levels and three reactor periods. Exhaust-nozzle chamber temperature and pressure were considered the primary engine variables to be controlled because of the relation to the engine specific impulse and thrust. Two methods of temperature control were investigated in terms of system dynamics: (1) the use of an inner-reactor-power control loop manipulated by a temperature controller and (2) direct manipulation of the control drums by the temperature controller with no direct control of reactor power. The results indicated that slightly better bandwidths could be achieved with the use of an inner-power loop. The power loop partly eliminated the restrictions imposed on the gain of the temperature controller by the effects of reactor period, thus allowing increased temperature-loop bandwidth. The effects of operating level on the response of the temperature loop were diminished by the use of adaptive-gain control. The linear analysis at the various operating levels was used to obtain a functional relation between the controller gain and chamber pressure for use in an adaptive controller (auth) (STAR)

125 (NASA-TM-X-1208) EXPERIMENTAL STUDY OF EFFECT OF SIMULATED REACTOR CORE POSITION ON NO₇/LE HEAT TRANSFER. Schmidt, James F., Bold-

man Donald R Ehlers Robert C , Coats, James W (National Aeronautics and Space Administration Cleveland, Ohio Lewis Research Center) Mar 1966 8p, CFSTI \$1 00 cy \$0 50 mn

A simulated reactor core was installed at various positions upstream from a conical nozzle in order to determine the influence of core position on nozzle heat transfer and boundary layer characteristics. The tests were conducted in an air facility at a nominal stagnation temperature and pressure of 9 0 R and 300 lb/in² respectively (auth)

126 (NASA-TM-X-1397) QADHD POINT-KERNEL RADIATION SHIELDING COMPUTER CODE TO EVALUATE PROPELLANT HEATING AND DOSE TO CREW DURING ENGINE OPERATION. Lahti, Gerald P. (National Aeronautics and Space Administration, Cleveland, Ohio Lewis Research Center), June 1967 90p, CFSTI.

A FORTRAN IV computer program QADHD, based on the LASL code QAD4, was written to evaluate the propellant heating in a nuclear rocket stage and to calculate the gamma and fast neutron doses received by a crew from the radiation emitted by the nuclear engine during the operating period. The QADHD is a combination of three codes QAD4 QADH and QADD. The LASL QAD4 is a general purpose program written to calculate gamma and fast neutron doses due to a volume-distributed source in a complex source-shield geometry that is generally describable by quadratic surfaces. QAD4 is a point-kernel code that employs infinite-medium buildup factors to calculate the gamma dose and employs the Albert-Welton kernel to calculate the fast neutron dose. The QAD4 included here was revised slightly from the LASL version to facilitate its use in the QADHD as well as to simplify data input. QADH utilizes the QAD4 routines to evaluate local heating throughout the propellant (and tank wall) and then integrates these heating rates over the entire volume of the propellant. Assuming that this heat is distributed uniformly throughout the propellant by natural convection (the complete-mix model) permits the rate of temperature rise of the propellant to be determined. QADH then determines the total temperature rise and accumulative heat input to the propellant as a function of reactor operating time. In some nuclear rocket configurations the propellant may serve to shield the crew from radiations emitted by the engine. In these cases QADD utilizes the QAD4 routines to calculate biological dose rates to the crew during engine operation while the propellant depth in the tank (or amount of shielding the propellant provides) changes with time. QADD then integrates these dose rates over engine operating time to obtain a total dose-time history (auth)

127 (NASA-TN D-2951) WHEEL-FLOW GASEOUS CORE REACTOR CONCEPT. Evvard John C. (National Aeronautics and Space Administration Cleveland Ohio, Lewis Research Center), Nov. 1965, 12p, CFSTI \$1 00 cy \$0 50 mn.

The wheel-flow gaseous-core reactor concept employs a cylindrical or toroidal core of hot fissioning uranium or plutonium fuel. This core is surrounded by a rotating annular region of propellant that enters and leaves the reactor tangentially. If the two flows rotate together as a wheel no shear will occur at the interface between the propellant and the fuel. Hence the fuel loss due to the mixing processes associated with shear would be minimized. Several reactor geometries employing or modifying the wheel-flow concept are suggested. These range from the basic cylindrical shape to toroidal geometries employing rotation about the jet axis to establish a radially outward centrifugal force. The stability problems in the flows and the possible use of magnetic fields and electric currents for damping of instabilities are briefly discussed (auth)

128 (NASA TN D-3197) RADIANT HEATING OF A SEEDED GAS IN A COAXIAL FLOW GASEOUS REACTOR. Masser Charles C. (National Aeronautics and Space Administration Cleveland Ohio Lewis Research Center) Jan 1966 24p CFSTI \$1 00 cy, \$0 50 mn

A theoretical analysis was made to determine how effectively a seed material can heat hydrogen propellant in a coaxial flow gas core reactor. It was assumed that the seed material was spherical and that the heat transfer mechanism was radiation from the hot gas core to the spherical particles and conduction from the particles to the surrounding hydrogen gas. The following ranges of conditions were used: particle diameters from 0 05 to 1 00 micron, power outputs of the gas core from 3195 to 10 037 Mw per foot of core length which correspond to surface blackbody temperatures of 30 000 and 40 000°R respectively, constant density and specific heat corre-

sponding to 500 atmospheres and 5500°R for the hydrogen propellant, and three values of hydrogen gas thermal conductivity corresponding to temperatures of 2900 5500 and 8000°R. It is concluded that the difference in temperature between the particle and bulk gas is such that the propellant seed mixture can be treated as a continuous gray gas (auth)

129 (NASA-TN-D-3771) DESIGN STUDY OF A REGENERATIVELY COOLED NOZZLE FOR A TUNGSTEN WATER-MODERATED NUCLEAR ROCKET SYSTEM. Puthoff Richard L (National Aeronautics and Space Administration, Cleveland Ohio Lewis Research Center) Dec 1966 34p Dep mn CFSTI \$3 00 cy \$0 65 mn

A regeneratively cooled nozzle was used for the tungsten water-moderated nuclear rocket (TWMR). The walls of the nozzle were cooled by hydrogen which was then used in the rocket system heat exchanger and topping turbine. A computer calculated a heat balance at predetermined stations along the nozzle axis. These calculations were summed over the entire nozzle length providing an integrated nozzle coolant pressure drop and temperature increase. To meet the design requirements set forth for the TWMR nozzle a parametric study was conducted. In the case of nozzle parameters such as coolant tube areas, tube thicknesses and number of coolant tubes, the effects of varying these parameters were felt most significantly by the nozzle ΔP_c (coolant pressure drop) with little effect on the ΔT_c (coolant temperature increase). Only when decreasing the inlet angle of the nozzle convergent section could a significant change in ΔT_c be effected. The tube stresses were also examined to determine the effect when varying these parameters. The design selected was designated the TWMR reference design. At 100 percent rocket power, the reference design nozzle coolant pressure drop is 132 3 pounds per square inch, coolant temperature increase 119 2°R and a maximum tube wall temperature of 1820°R. Nozzle performance calculations were also made at rocket reduced power conditions. Although the nozzle design presented is unique to the TWMR rocket engine, the principles involved are applicable to other nuclear rocket designs (auth)

130 (NASA-TN-D-3840) MAPPING A TUNGSTEN-REACTOR ROCKET ENGINE AS A GUIDE TO OPERATION AND CONTROL. Cavicchi Richard H. (National Aeronautics and Space Administration, Cleveland Ohio Lewis Research Center) May 1967 89p CFSTI

A one-dimensional nonlinear analog simulation of a preliminary tungsten water moderated reactor system was used to map system performance over a wide range of steady-state operation. Mapping was conducted by using hydrogen mass flow rate and chamber temperature as independent variables. These parameters were varied over a range from 20 to 120% and from 67 to 135% of design respectively. The steady state maps obtained are interpreted and conclusions are drawn concerning various aspects of system operation and control. (H D R)

131 (NASA-TN-D-3931) COOLDOWN CHARACTERISTICS OF REGENERATIVE NOZZLE USED IN FULL-SCALE, COLD-FLOW, NUCLEAR ROCKET TEST FACILITY. Turney, George E., Cox, Eileen. (National Aeronautics and Space Administration, Cleveland Ohio Lewis Research Center) May 1967 60p CFSTI

Transient pressure drop heat transfer characteristics of a regeneratively cooled nozzle subassembly used in startup tests conducted with a full-scale unfueled nuclear rocket simulation system were made from both analytical and experimental standpoints. The pressure drops and heat transfer rates with gaseous two phase and subcooled liquid hydrogen flow in the nozzle assembly were computed and compared with experimental measurements (M L S)

132 (NASA-TN-D-3979) FREQUENCY RESPONSE AND TRANSFER FUNCTIONS OF A NUCLEAR ROCKET ENGINE SYSTEM OBTAINED FROM ANALOG COMPUTER SIMULATION. Hart Clint E., Arpaio Dale J. (National Aeronautics and Space Administration Cleveland Ohio Lewis Research Center) May 1967 39p CFSTI

The dynamic response characteristics of the basic variables of a NERVA-type nuclear rocket engine system are presented. Frequency-response data at four selected operating levels were obtained from a detailed analog computer simulation. Frequency responses of thrust chamber temperature, chamber pressure and reactor power to pertinent control or system variables are shown. Transfer functions that approximate the frequency responses are presented. The effect of reactor period on the reactor-power transfer function was investigated and transfer functions are presented. These results provide essential information for control system analysis and design. The analytical models and assump-

tions used to develop the equations that represent the dynamics of nuclear rocket engine components are discussed. A set of specific equations that can be used in an analog computer simulation is presented (auth)

133 (NASA-TN-D-4093) CONTROL OF A NUCLEAR REACTOR WITH A GASEOUS CONTROL SYSTEM. Davison, Harry W.; Heath, Colin A.; Lowen, Walter (National Aeronautics and Space Administration, Cleveland, Ohio, Lewis Research Center). Aug. 1967. 68p. CFSTI.

A control system concept utilizing a neutron-absorbing gas, ^3He was investigated for use with a water-moderated reactor. A static gas system is finely distributed throughout the reactor core to minimize flux depression effects by the control medium. Reactivity control is performed by controlled pressurization of the He gas. Investigations have been performed in the areas of ^3He containment and thermal and neutronic stability during operation. Although there is some probability that leaks could occur in the control system, the rate of loss of He can be limited such that the reactor can be shutdown before it is damaged. Potential accident situations are limited by using flow restricting orifices in the system and by providing a positive water pressure seal on the control system. The possibility of positive power coefficients of reactivity with a gaseous poison system was examined. Power coefficients of reactivity can be made small, and in some cases negative, by careful design. Configurations of a control element with small temperature and density gradients and a distribution system that provides a negative power coefficient are presented. The concept of reactor control with ^3He in metal control elements located in the moderator region appears feasible for the system investigated (auth)

134 (NASA-TN-D-4127) HEAT- AND MASS-TRANSFER CHARACTERISTICS OF AN AXIAL-FLOW LIQUID-CORE NUCLEAR ROCKET EMPLOYING RADIATION HEAT TRANSFER. Ragsdale, Robert G.; Kascak, Albert F.; Donovan, Leo F. (National Aeronautics and Space Administration, Cleveland, Ohio, Lewis Research Center). Aug. 1967. 46p. CFSTI.

An analysis of heat- and mass-transfer processes was conducted for a liquid-core nuclear rocket engine that employs radiation heat transfer. A liquid carbide fuel was supported on the inside surface of a rotating tube. The hydrogen propellant, seeded with radiation-absorbing seed material, flowed through the tube where it was heated by thermal radiation from the fissioning liquid fuel. Liquid-fuel surface temperature, U concentration in the fuel, tube length and diameter, and H_2 flow rate were the primary variables. Calculations were made for both ZrC and NbC solvents in which UC was dispersed. The calculations show that radiant heating produces a specific impulse somewhere between the lowest value of interest, 1300 seconds, and the maximum attainable, about 1600 seconds—a value that is only marginally higher than that provided by conduction heating of H_2 bubbled through the liquid fuel. The ratio of H_2 flow rate to U flow rate is from about 20 to 100, depending on flow-rate ratio, reactor pressure, tube diameter, and thrust to core-weight ratio. The thrust to core-weight ratio is between 3 and 13. The surface temperature of the liquid fuel must be maintained between 9000 and 10,000°R in order to attain a specific impulse in the range of interest (auth)

135 (NASA-TN-D-4164) ESTIMATES OF LOCAL AND AVERAGE FUEL TEMPERATURES IN A GASEOUS NUCLEAR ROCKET ENGINE. Kascak, Albert F. (National Aeronautics and Space Administration, Cleveland, Ohio, Lewis Research Center). Sept. 1967. 29p. CFSTI.

A diffusion analysis is presented of the radiant heat transfer from a centrally located cylinder of gaseous nuclear fuel to a surrounding annulus of flowing hydrogen. Results are shown as radial temperature profiles and integrated average temperatures in the fuel region. Parametric calculations are presented to show the influence on fuel temperature of boundary conditions, radial fuel profiles, fuel ionization and density profiles, the fuel absorption coefficient, reactor pressure, and engine thrust. All calculations are for a specific impulse of 1500 seconds, engine thrust is varied from 10^5 to 10^6 pounds which corresponds to reactor powers from 4000 to 40,000 megawatts. Most results are presented for a thrust of 500,000 pounds and a reactor pressure of 500 atmospheres, but a final set of average fuel temperatures are also presented for pressures of 100, 500, and 1000 atmospheres and a thrust ranging from 10^5 to 10^6 pounds. For a given engine configuration, thrust, specific impulse, and power level, it is shown that boundary conditions of fuel zone edge location and fuel temperature do not significantly affect the average fuel temperature. Fuel ionization and perfect gas density variation with local temperature are likewise relatively unimportant influences on either internal or average fuel temperatures. Using a radially decreasing fuel mole fraction profile in place of a constant radial fuel mole fraction distribution reduces the average fuel temperature from 107,000° to 93,000°R.

Results include only the influence of radiative transfer, a significant degree of turbulent heat transport or electron conduction would decrease estimated fuel temperatures (auth)

136 THE CONTROL OF A NUCLEAR REACTOR USING ^3He GAS CONTROL ELEMENTS. Davison H W (Lewis Research Center, Cleveland), Heath, C A., Lowen, W. Trans Amer Nucl Soc 9 574-5 (Oct-Nov 1966)

137 EFFECT OF TURBULENCE ON RADIANT HEAT TRANSFER IN A GASEOUS-CORE NUCLEAR ROCKET ENGINE. Kascak, Albert F. (Lewis Research Center, Cleveland). Trans. Amer. Nucl. Soc., 10: 354-6 (June 1967).

From 13th Annual Meeting of the American Nuclear Society, San Diego, Calif., June 11-15, 1967. See CONF-670602.

138 FLOW SYSTEM STARTUP OF A FULL-SCALE SIMULATED NUCLEAR ROCKET ENGINE. Colmery, Benjamin H.; Powers, Albert G. (National Aeronautics and Space Administration, Cleveland). IEEE (Inst. Elec. Electron. Eng.), Trans. Nucl. Sci., NS-13: No. 1, 655-62 (Feb. 1966).

The performance of the liquid hydrogen flow system during the startup transient of a nuclear rocket was measured in a full-scale simulated engine system. In flight exhaust conditions were approximated by maintaining a nozzle outlet pressure of 1 psia. Data and general conclusions on overall system performance are presented for nonnuclear operation. The ability of the rocket system to bootstrap (i.e., to build up appreciable hydrogen flow and pressure in the nuclear reactor without extra-system assistance) was clearly demonstrated by using only the energy from hydrogen tank pressure and latent heat of engine components. The severity (small) and characteristics of two-phase flow oscillations during windmill were determined. No significant operating problems were encountered (auth)

139 PERFORMANCE LIMITATIONS ON A RADIATING LIQUID-CORE NUCLEAR ROCKET DUE TO SUPPORT-WALL TEMPERATURE REQUIREMENTS. Putre, Henry A. (Lewis Research Center, Cleveland). Trans. Amer. Nucl. Soc., 10: 356 (June 1967).

From 13th Annual Meeting of the American Nuclear Society, San Diego, Calif., June 11-15, 1967. See CONF-670602.

Naval Radiological Defense Laboratory, San Francisco, Calif.

140 (USNRDL-TR-1046) RADIONUCLIDE RELEASE FROM AEROSPACE NUCLEAR REACTOR FUELS V PHASE TWO PULSED NEUTRON IRRADIATION OF FUEL IN WATER. Weisbecker, L W., Lai, M G., Goya, H A., Cordova, H I (Naval Radiological Defense Lab., San Francisco, Calif.). May 24, 1966. Contract AT(49-5)-2084. 64p. Dep. mn. CFSTI \$3 00 cy, \$0 75 mn.

Accidental seawater immersion of a NERVA/ROVER type core would result in a criticality excursion, releasing fission product radionuclides to the environment. In order to simulate the excursion situation and to study the resulting radionuclide release, specimens of NERVA/ROVER fuel were irradiated under different pulsed neutron conditions in a TRIGA Mark F reactor, the KEWB reactor, and the KIWI-TNT reactor excursion test. Most of these specimens were irradiated immersed in water. Under these conditions, measurements were made of (1) the fission product inventories of fuel specimen and environmental water, (2) internal capsule pressure generated, (3) fuel body and microstructure damage, and (4) leaching properties of irradiated fuel. Irradiation effects of greater than moderate significance occurred only in the fuel specimen irradiated most severely in the KIWI-TNT reactor excursion test. Release of fission products to the water appeared to be a function of exposed surface area of the fuel and was less dependent on specimen specific fissioning for both long-term leaching after irradiation and during irradiation. Fission product fractionation in the fuel was a function of the specimen specific fissioning. All fission products which fractionated, except ^{131}I , have a volatile precursor (auth)

141 (USNRDL-TR-1082) BETA DOSE RATES FROM NEUTRON-IRRADIATED ^{235}U CARBIDE PARTICLES. Pestaner, J. F.; Kubose, D. A.; Balkwell, W. R. (Naval Radiological De-

fense Lab., San Francisco, Calif.). June 30, 1966. Contract AT(49-5)-2505. 29p. Dep. mn. CFSTI \$3.00 cy, \$0.65 mn.

Small highly radioactive particles could be injected into the biosphere from the reentry and burnup of a nuclear propulsion reactor. This would constitute a potential radiological hazard to man. The experimental measurement of beta dose rates from fission products contained in pyrolytic-carbon-coated uranium-235 carbide beads of core diameter 90, 120, and 260 μ is reported. The dose was measured in an extrapolation chamber using tissue equivalent electrodes. The beta dose from the irradiated particles delivered to a segment of tissue can be calculated using a rate law derived from the experimental values. (auth)

142 (USNRDL-TR-1090) ANALYSIS OF DEBRIS FROM APG-3, THE SIMULATED DESTRUCT SYSTEM TEST OF A FULL-SCALE ROVER/NERVA REACTOR. O'Connor, Joseph D.; Scheidt, Ronald C.; Pascual, Juan N. (Naval Radiological Defense Lab., San Francisco, Calif.). June 24, 1966. Contract AT(49-5)-2505. 42p. Dep. mn. CFSTI \$3.00 cy, \$0.65 mn.

Analysis of fragments from one of four jets of debris of a high-explosive destruct test of a nuclear reactor showed that the distribution of weight with particle size was bimodal with a major peak near 4 mm and a minor peak near 0.2 mm. The distribution of activity also was found to be bimodal, with a more pronounced peak at 0.2 mm. Specific activity calculations showed that the peak centered about the 0.2 mm size range contained the debris that was the most highly enriched in uranium. Little uranium activity was noted in particles below this size. Comparison with results of other investigations showed that a small sampling effort such as was undertaken provides adequate sampling of the debris from one jet. However, variation in particle characteristics from one jet to another would require sampling all jets in a future operation. (auth)

143 (USNRDL-TR-1100) RADIOCHEMICAL AND PHYSICO-CHEMICAL STUDIES OF KIWI-TNT DEBRIS. Lai, John R.; O'Connor, Joseph D.; Crocker, Glenn R.; Pascual, Juan N.; Freiling, Edward C. (Naval Radiological Defense Lab., San Francisco, Calif.). Sept. 28, 1966. Contract AT(49-5)-2505. 136p. Dep. mn. CFSTI \$3.00 cy, \$0.65 mn.

Five samples of debris from the Kiwi-TNT event were studied for properties relating to biological hazard, particle properties, radiation properties, radiochemical composition and radionuclide solubility. The samples examined were three cloud samples, one ground-filter sample and a fallout sample. The particles in the cloud and ground-filter samples were in the 10 to 100 micron size range and were mixed with varying amounts of extraneous material (desert dust). In the fallout sample, the bulk of the particles were irregularly shaped, although some spheroids were present. The particles were mainly graphite and the sizes ranged from several microns to several millimeters. Gross gamma decay rates exhibited negative logarithmic exponents ranging from 0.73 to 1.76. The gamma-ray spectra of the three cloud samples were similar, but otherwise significant differences were found from sample to sample. Radiochemical analysis showed that the ground-filter sample was highly enriched in volatilely behaving fission products ($^{89,90}\text{Sr}$, ^{131}I , ^{132}Te , ^{137}Cs). The cloud samples were somewhat enriched in volatiles, but relatively representative. The fallout sample showed a depletion of volatiles. This depletion increased as the particle size diminished and as the particle shape became more spheroidal. The fractionation behavior was quite similar to that observed in weapon debris, as was the dependence of fractionation on particle shape. The dependence of fractionation on particle size in the fallout sample, however, was the opposite of that observed in weapon debris and indicates the operation of different fractionation mechanisms. Distilled water, 0.8% saline and 0.1N HCl were tested for their ability to leach activity from the debris. The water and saline solutions were found to have comparable, but low, leaching abilities. The acid had a greater leaching effect than either of these solutions. However, the difference in leaching ability between the acid and other liquids was found to decrease with decreasing particle size. This property was also observed for weapon debris. The soluble activity consisted predominantly of $^{89,90}\text{Sr}$, ^{91}Y , ^{131}I , ^{132}Te and ^{140}Ba . (auth)

144 DOSE MODELS FOR EVALUATING THE RADIATION HAZARD FROM REACTOR DEBRIS. Ellett, W. H. (Naval Radiological Defense Lab., San Francisco); Berger, M. J.; Hogan, O. L. Trans. Amer. Nucl. Soc., 8: 568 (Nov. 1965).

145 RADIONUCLIDE FRACTIONATION AND LEACHING OF TRANSIENT NUCLEAR TEST DEBRIS. Lai, J. R.; Freiling, E. C. (Naval Radiological Defense Lab., San Francisco). Trans. Amer. Nucl. Soc., 10: 3-4 (June 1967).

From 13th Annual Meeting of the American Nuclear Society, San Diego, Calif., June 11-15, 1967. See CONF-670602.

New Mexico University, Albuquerque

146 (SC-CR-66-2017) ROVER DESTRUCT TEST THREE, ABERDEEN PROVING GROUND. Final Report. Castonguay, T. T.; Anderson, T. B.; Bower, R. C. (New Mexico Univ., Albuquerque). Dec. 1965. Contracts AT(29-1)-789; 48-2512. 15p. Dep. mn. CFSTI \$1.00 cy, \$0.50 mn.

For Sandia Corp., Albuquerque, N. Mex.

Particle collection and sizing are reported from the ROVER destruct test. These data are expected to provide a few of the inputs to a computer program designed to analyze particle distribution from a space destruct of the ROVER/NERVA propulsion engine. These data were obtained from polystyrene blocks containing graphite particles, which were dissolved in trichloroethylene. The graphite particles were collected, cleaned and sized through a series of Tyler sieves. Graphite particles embedded in rotating polystyrene plastic were also recovered and sized, but prior to dissolving, the angle of entry and depth of penetration were tabulated. (auth)

147 (SC-DC-67-1916) MODERN CONTROL APPLICATIONS TO NUCLEAR PROPULSION. Mohler, Ronald R. (New Mexico Univ., Albuquerque). July 1967. Contract AT(29-1)-789. 15p. (CONF-670710-3). Dep. CFSTI. From American Astronautical Society Symposium, Denver, Colo.

Fuel-optimal control of a nuclear propulsion system is analyzed by means of the maximum principle. Lagrange multipliers and computers. Practical problems are shown to be most complicated by state constraints and high dimensionality. The optimal policy a maximum allowable effort type of process, requires a time-optimal reactor control policy. With this in mind, a minimal-time, prompt-neutronic control process with reactivity rate and amplitude constraint is analyzed. (auth)

148 (SC-CR-67-2746) OPTIMAL NUCLEAR REACTOR CONTROL. Technical Report EE-142. Mohler, R. R.; Price, H. J. (New Mexico Univ., Albuquerque. Bureau of Engineering Research). Aug. 1967. Contracts AT(29-1)-789; 53-4757. 162p. Dep. CFSTI.

For Sandia Corp., Albuquerque, N. Mex.

Topics discussed include: theoretical aspects and numerical calculation of optimal controls with the maximum principle for the nuclear rocket reactor; potentially singular subarcs for the nuclear rocket reactor; and linear programming with MPS 1360. (D.C.C.)

149 (SC-CR-67-2723) COMPUTATION OF OPTIMAL CONTROLS FOR A NUCLEAR ROCKET REACTOR. Price, H. J.; Mohler, R. R. (New Mexico Univ., Albuquerque. Dept. of Electrical Engineering). Sept. 1967. Contract AT(29-1)-789. 32p. Dep. CFSTI.

Various optimal reactor control problems with complicated constraints are solved for a nuclear rocket engine. The technique utilizes a digital computer with the numerical algorithm formed by a succession of linear programming problems. Each programming problem has a solution which is used to relinearize the system's dynamical equations. (auth)

NUS Corp., Washington, D. C.

150 (NUS-208) ENVIRONMENTAL SAFETY ASPECTS OF NUCLEAR ROCKET FLIGHT OPERATIONS. Semi-Annual Progress Report, May-October 1964. (Nuclear Utility Services, Inc., Washington, D. C.). Dec. 1964. Contracts AT(11-1)-651; SNPC-6. 64p. Dep. mn. CFSTI \$3.00 cy, \$0.75 mn.

The work conducted during this period is divided into two major categories: Ground Safety Program Activities and Flight Safety Program Activities and Flight Safety Program Activities. The Ground Safety activities include: NRDS effluent work; modification and application of the NURSE-1 computer program to the NRDS situation; NRDS Safety Advisory Panel activities; and a preliminary study of effluent decontamination. The Flight Safety activities include: those generated by assignment under the Radiological Effects Working Group; the examination and development of models

for the description of particle velocities created by destruct action; and work on nuclear transient codes (auth)

151 (NUS-229(Rev.)) DOSE CALCULATION MODELS FOR RE-ENTERING NUCLEAR ROCKET DEBRIS. DeAgazio, Albert W. (NUS Corp., Washington, D. C. Environmental Safeguards Div.). May 12, 1965. Revised Jan. 1967. Contract SNPC-6. 51p. Dep. CFSTI.

Estimation of the biological hazards resulting from nuclear rocket engine flight failures is complicated by the more or less random nature of the deposition of engine debris into the biosphere. The debris may come to earth in an uninhabited desert or in the midst of a large city. In the first case, the probability of direct exposure of individuals to the debris will be vanishingly small, whereas in the latter case the probability may be extremely high. Similarly, the probability of indirect exposure through ingestion is directly related to the likelihood of the debris falling on cultivated land. The probabilistic approach to the evaluation of dose was initially treated in an earlier report, NUS-167, and much of this report is a refinement of that work. The external dose functions and external and internal dose probability functions are derived in this report. External whole body gamma and beta dose relationships are derived for receptors who are mobile; i.e., who are not fixed in a given location for the entire exposure period.

The probability of receiving at least a given external dose, the fraction of the population receiving at least a given dose and the overall population dose are also derived for external gamma radiation exposures. The functions for determining the probability of a receptor being struck by a particle that sticks to the skin and the number of people so affected are derived to allow estimation of the hazard from localized beta doses to the skin. Internal dose probability functions are derived for both ingestion and inhalation. These relations consider cultural influences such as diet, agricultural production, and population density. Functions for estimating critical organ doses resulting from plant uptake and subsequent ingestion are not derived in this report because of the variations in soil characteristics, dietary intake and cooking and eating habits that exist throughout the world. Comparisons are made, however, to fallout from nuclear weapon testing and subsequent appearance of ^{90}Sr and ^{137}Cs in food in the United States (W.E.B.)

152 SAFETY ASPECTS OF GROUND TESTING FOR LARGE NUCLEAR ROCKETS. Goldman, Morton I. (NUS Corp., Washington, D. C.). Nucl. Appl., 2: 94-8 (Apr. 1966).

Present effluent prediction techniques are applied to ground tests of advanced nuclear rocket engines that will be forthcoming in several years. If the future fuel performance is assumed to be substantially the same as at present, it is shown that effluent decontamination will be required to maintain the present safety record with longer running times and higher reactor-power levels (auth)

Oak Ridge National Laboratory, Tennessee

153 (ORNL-3970, pp 236-44) ROVER ROCKET NOZZLE MATERIALS. Franco-Ferreira, E. A. (Oak Ridge National Lab., Tenn.).

The short-time tensile properties and joinability of eight alloys were investigated. These are Inconel X-750, Inconel 718, René 62, Hastelloy X, Hastelloy N, Inconel 625, IN-102, and type 347 stainless steel. In addition, the thermal conductivities of Hastelloy X, Hastelloy N, Inconel 625, and Inconel 702 were estimated. These materials are all candidates for nuclear rocket nozzle fabrication. Also, a method for nondestructively testing tapered thin-wall tubes was developed. (auth)

154 (ORNL-TM-1159) ENVIRONMENTAL STUDIES: RADIOLOGICAL SIGNIFICANCE OF NUCLEAR ROCKET DEBRIS. Semiannual Progress Report, January 1-June 30, 1965. Fish, B. R.; Clark, T. G.; Boyett, R. H.; Wilkie, W. H. Jr.; McWhorter, W. C.; Thompson, J. L. (Oak Ridge National Lab., Tenn.). Jan. 1966. Contract W-7405-eng-26. 44p. Dep. mn. CFSTI \$3.00 cy, \$0.65 mn.

Radiological safety studies were continued to determine the hazards which might result from radioactive debris from an accidental fragmentation of a nuclear rocket in space. The studies included the production of micron size particles, dosimetry of such particles which were made radioactive, the effects of the radioactive particles on body tissues, and a computer program for estimating tissue depth doses from reactor debris. The production of minute particles containing ^{89}Sr to simulate reactor debris is described in detail. A technique for inserting these particles into organisms is given. (L.C.L.)

Public Health Service, Las Vegas, Nev. Southwestern Radiological Health Laboratory

155 (CONF-660621-7) RADIOIODINE STUDIES FOLLOWING THE TRANSIENT NUCLEAR TEST (TNT) OF A KIWI REACTOR. Barth, D. S.; Black, S. C. (Public Health Service, Las Vegas, Nev. Southwestern Radiological Health Lab.). [1965]. 14p. Dep. mn. CFSTI \$2.00 cy, \$0.50 mn.

From Health Physics Society, 11th Annual Meeting, Houston, Tex.

In conjunction with the Transient Nuclear Test of a Kiwi reactor, hay contamination and controlled dairy cow ingestion studies for radioiodines were conducted. The study was designed to simulate the maximum possible radioiodine uptake by dairy cows from typical winter dairy farming practices where radioiodines enter the cows via ingested contaminated hay. The kinetics of the secretion of radioiodines in milk under the conditions of this experiment were determined. Peak values of 830 pCi/liter for ^{131}I and 150 pCi/liter for ^{134}I were observed in milk of individual cows. For ^{131}I the effective decay half-life in the milk of one group of cows during feeding of contaminated hay was found to be 5.5 days, whereas for another group it was 2.8 days (auth)

Rensselaer Polytechnic Institute, Troy, New York

156 (CONF-650413, pp 182-205) CONTROL OF ABSORPTION CROSS SECTION FOR A NUCLEAR ROCKET. Shen, C. N.; Liu, T. C. (Rensselaer Polytechnic Inst., Troy, N. Y.).

The two-energy-group and one delayed-neutron-group kinetics equations with approximations are applied to the nuclear rocket. The response of the neutron flux and precursors having optimum control under different starting conditions is determined and plotted. (G.O.Y.)

157 TRANSIENT HEAT TRANSFER AND THERMAL STRESSES FOR A NUCLEAR ROCKET DUE TO SUDDEN INCREASE OF COOLANT FLOW. Shen, C. N.; Liu, T. C. (Rensselaer Polytechnic Inst., Troy, N. Y.). New York, American Society of Mechanical Engineers, 1966, Preprint No. 66-WA/NE-4, 10p., \$1.50. (CONF-661102-30). DTIE.

From American Society of Mechanical Engineers, Winter Annual Conference, New York.

The analytical solutions of the thermal transient and thermal stresses are derived for a sudden change of the coolant flow in a nuclear rocket. These solutions are suitable for two geometric configurations of fuel elements which are commonly encountered in nuclear-rocket design (auth)

158 (N-65-30544) CONTROL OF ABSORPTION CROSS SECTION FOR A NUCLEAR ROCKET. Shen, C. N.; Liu, T. C. (Rensselaer Polytechnic Inst., Troy, N. Y. Dept. of Mechanical Engineering). Apr. 1, 1965. 33p. (NASA-CR-64248; AC-3). CFSTI \$2.00 cy, \$0.50 mn.

The two energy and one delayed-neutron group kinetics equations with approximations are employed for the nuclear rocket. The perturbation equations for kinetics are derived with the assumption that the deviation from the reference flux are small in comparison with the reference values. The temperature effect due to the change of the Fermi age may be compensated by a feedback loop. The absorption cross section is changed accordingly so that the system will be made independent of the effect of temperature variation. The spatial distribution of the flux and precursor are assumed to be sinusoidal in the axial direction of the nuclear rocket. The reduced kinetics equations are obtained from the perturbed equation by introducing exponential weighting function. The index of performance is chosen to be the integral of the square errors on perturbed neutron flux and the control effort. Maximum principle is used to derive the control laws which in turn determines the absorption cross section, using the measured flux as feedback with a variable gain. The response of the flux and precursor having optimum control under different starting conditions is determined and plotted (STAR)

159 (N-66-39722) TRANSIENT DYNAMICS AND THERMAL STRESS FOR NUCLEAR ROCKET HEAT-EXCHANGER. Liu, T. C.; Shen, C. N. (Rensselaer Polytechnic Inst., Troy, N. Y. Dept. of Mechanical Engineering). Sept. 7, 1966. 77p. (NASA-CR-78947). CFSTI \$3.00 cy, \$0.65 mn.

The equivalent one-dimensional approach for the transient heat transfer problem in a nuclear reactor is discussed in detail. From this approach, the temperature distribution of fuel element and coolant channel are obtained in simple form and with sufficient accuracy. The transient thermal stresses are proportional to the difference of temperature between the fuel element and coolant channel. The analytical solutions of the thermal transient and stresses are given for a sudden change of the hydrogen flow. From several numerical examples, it is shown that the transient thermal stresses can be much higher than the steady-state full power thermal stresses. The maximum transient to steady-state full power thermal stresses should be limited to a proper ratio to ensure that the design of the reactor is within the margin of safety (STAR)

160 DISTRIBUTED PARAMETER OPTIMUM CONTROL OF A NUCLEAR ROCKET WITH THERMAL STRESS CONSTRAINTS. Briggs, D. L.; Shen, C. N. (Rensselaer Polytechnic Inst., Troy, N. Y.). J. Basic Eng., 89. 300-6 (June 1967).

Control of coolant flow-rate through a nuclear rocket is considered. Temperature gradients in the fuel elements, and the correspondingly produced thermal stresses, are analyzed. The system equations are a pair of coupled, first-order, bilinear, partial differential equations which describe the steady-state. Analysis of the solution for a step in control and the coupling between control level and time response gives the needed form of optimal control. Use of the digital computer in generation of the optimal control law is discussed. Numerical results are given (M L S)

161 AN INVESTIGATION OF OPTIMUM CONTROL FOR NUCLEAR ROCKETS [Thesis]. Haag, Fred George. Troy, N. Y., Rensselaer Polytechnic Inst., 1964. 177p.

The methods of optimum control theory are applied to nuclear reactor control. The optimum control of both reactor power and reactor temperature is considered. A simplified form of the reactor kinetics equations is derived, which is suitable for application of optimization techniques. The start-up problem is cast into a "quasi-linear" form by introduction of a logarithmic power variable. The mechanism

Rocketdyne, Canoga Park, Calif.

162 (CONF-671009-1) DUAL TURBOPUMP LIQUID HYDROGEN FEED SYSTEM EXPERIENCE. Gunn, S. V.; Dunn, C. (Rocketdyne, Canoga Park, Calif.). [nd]. Contracts SNP-2; NASw-347; NASw-1210; CTZ-39600-2. 29p. Dep. CFSTI.

From 9th Liquid Propulsion Symposium, St. Louis, Mo. Experience in the design and development of liquid hydrogen feed systems utilizing two turbopumps operating in parallel is described. The pumps are supplied with liquid hydrogen from a common inlet and discharge into a common duct, the turbines also are supplied with turbodrive gases from a common inlet. Two system configurations were designed, developed, and delivered, one having dual Mark 9 turbopumps and one having dual Mark 25 turbopumps. The systems deliver flows up to 330 lb/sec and pressures up to 2000 psi. They were developed for use in Phoebus reactor testing performed by the Los Alamos Scientific Laboratory. Component and system performance, and dynamic characteristics of the systems are described. Development tests have proved the practicality of parallel dual, liquid hydrogen turbopump operation. The two units operate with complete hydrodynamic stability, sharing the hydraulic load equally, and no detrimental mechanical interactions have been found. Dual turbopumps offer the potential of emergency, single pump operation. The current feed system has a check valve in each pump discharge prior to the common header, and the potential for such emergency operation is being evaluated. (auth)

Sandia Corporation, Albuquerque, New Mexico

163 (SC-DC-65-1752) AEROSPACE NUCLEAR SAFETY. Blake, V. E. Jr. (Sandia Corp., Albuquerque, N. Mex.). Sept. 22, 1965. Contract AT(29-1)-789. 13p. (CONF-651026-1). Dep. mn; CFSTI \$1.00 cy, \$0.50 mn.

From 1st AIAA Rankine Cycle Space Power System Specialists Conference, Cleveland.

A brief history of the introduction of nuclear power into space and the results of early flights are presented. The problem of safety is discussed, as well as the direction taken by early designers to achieve safety. The discussions also cover alternate approaches to safety which were initially considered. There is a discussion of power supplies currently under development, and the approaches being followed to achieve safety. A series of charts is presented which categorize the main safety approaches, and will provide the basis for a systematic safety assessment. Finally, a safety philosophy for future design is presented. It is shown that safety is not the responsibility of any one agency but rather a problem of all (M O W)

164 (SC-R-65-1017) AEROSPACE SAFETY RESULTS FROM A ROVER/NERVA POST-OPERATIONAL DESTRUCT TEST. Berry, R. E. (Sandia Corp., Albuquerque, N. Mex.). Nov. 1965. Contract AT(29-1)-789. 17p. (CONF-651101-54). Dep. mn. CFSTI \$1.00 cy, \$0.50 mn.

From 13th Conference on Remote Systems Technology, Washington, D. C.

The destruction of a full-scale mockup ROVER/NERVA propulsion engine was performed under the direction of the joint AEC/NASA Space Nuclear Propulsion Office. The data collected included information about the destruct debris velocity, size, weight, and spatial distribution. These data are a satisfactory source term for the computer analysis of the ROVER/NERVA Program safety. (auth)

165 (SC-RR-65-557) EVALUATION OF MICROSCOPIC-SIZED GRAPHITE AEROSOL FROM A ROVER REACTOR DESTRUCTION TEST, JUNE 1965. Parker, D. R. (Sandia Corp., Albuquerque, N. Mex.). Dec. 1965. Contract AT(29-1)-789. 15p. Dep. mn. CFSTI \$1.00 cy, \$0.50 mn.

The methods used to evaluate the environmental health aspects of particle dispersion and properties following the destruction of a full-scale model of a ROVER-NERVA reactor are summarized. The methods used to collect airborne samples and to analyze the particles are described. Results on the total number and the size distribution of the particles are included (D.C.W.)

166 (SC-RR-65-551) ROVER POSTOPERATIONAL DESTRUCT INSTRUMENTATION DEVELOPMENT. Berry, R. E.; Martin, J. P. (Sandia Corp., Albuquerque, N. Mex.). Dec. 1965. Contract AT(29-1)-789. 119p. Dep. mn. CFSTI \$4.00 cy, \$1.00 mn.

Development tests in preparation for a full-scale destruct test of the ROVER/NERVA space propulsion engine are reported. The development tests furnish the following information: the debris pattern from a four-explosive-charge scale model is a four-jet pattern with the jets originating at 45 degrees between the explosive charges, the debris size and distribution is repeatable and the size ranges from 0.5 to 4760 microns, the velocity of the debris particles is about 350 to 450 feet per second, scale models simulating the real item must be used to be assured of proper debris distribution pattern, rotating polystyrene foam particle catchers and velocity measuring devices are satisfactory and will yield the desired data, air sampling is necessary to obtain information on the particle sizes below 20 microns, 2-pound per cubic foot foam is superior for particle collection, and the pressure generated is about 50 percent of the pressure created by an uncased charge of the same weight. The development tests provide techniques, instrumentation, and physical layout information needed for performing a full-scale destruct test on a mockup ROVER/NERVA space propulsion engine (auth)

167 (SC-RR-65-620) ROVER/NERVA DESTRUCT SYSTEM TEST RESULTS, ABERDEEN PROVING GROUND-3 (FINAL REPORT). Berry, R. E.; Martin, J. P. (Sandia Corp., Albuquerque, N. Mex.). Dec. 1965. Contract AT(29-1)-789. 258p. Dep. mn. CFSTI \$6.00 cy, \$1.25 mn.

A full-scale destruct test of the ROVER/NERVA space propulsion engine was made. In the test, a full-scale mock-up of the ROVER/NERVA was destroyed by four statically emplaced, 105 mm special explosive charges. The information and data obtained from the test were to

establish the spatial distribution of particles, the size distribution as a function of the mass, and velocity. The instrumentation for the full-scale destruct test successfully obtained the desired data. Particle sizes up to 20 microns were obtained by air sampling, but these small particles did not contain uranium. Pressure measurements obtained were 23 psi at 20 feet, 8 psi at 30 feet, and 4.2 psi at 40 feet. Graphite debris velocity recorded was 570 fps over 20 feet, however, the debris velocity dropped to 420 fps over 70 feet. Part of the debris from this test was distributed radially, and the remainder was dispersed in five concentrated jets. The metallic components (skin, reflectors, and control drums) were deployed in a symmetrical radial pattern, and each numbered component moved on a radial line from its location prior to the destruct test. The core and graphite reflector did not follow the radial pattern but flowed within the core cavity and were deployed in four horizontal jets, 90° apart, and in a vertical jet. Results are included (auth)

168 (SC-RR-66-589) ROVER/PHOEBUS SCALED MODEL CHEMICAL EXPLOSIVE DESTRUCT TEST RESULTS. Berry, R. E. (Sandia Corp., Albuquerque, N. Mex.). Dec. 1966. Contract AT(29-1)-789. 55p. Dep. mn, CFSTI \$3.00 cy, \$0.65 mn.

The ROVER/PHOEBUS scaled model tests were performed to evaluate the safety aspects of nuclear power supplies being proposed for space application. Three tests were performed to provide base level or comparative data about the destruct event under controlled conditions. Data about the debris cloud shape, metallic parts distribution, and graphite particle size distribution were collected from these tests. Future testing to determine the effects of nonsimultaneous firing of the explosive charges, varying the explosive entry angle into the core, and destroying the model with the core heated to near reactor operating temperature were delayed pending a redirection of the program when the results from the control tests indicated that with the present explosive weight, perturbations would not be observable. During the delay period, the explosive destruct mode of disposal became less attractive, and the test program was canceled (auth)

169 AEROSPACE SAFETY RESULTS FROM A NERVA POST-OPERATIONAL DESTRUCT TEST. Clark, A. J. Jr., Berry, R. E. (Sandia Corp., Albuquerque, N. Mex.). Trans. Amer. Nucl. Soc., 8: 566(Nov. 1965).

170 SPACE NUCLEAR SAFETY 1966. Hansen, H. E. (Sandia Lab., Albuquerque, N. Mex.). Nucl. Safety 8: 1-11(Fall 1966).

A general survey is presented of the state of space nuclear safety studies. The recently formed AEC Division of Space Nuclear Systems, which has responsibility for all space nuclear power and propulsion system development, is described. A systematic approach to space nuclear safety analysis is presented, and a basis for acceptable safety guidelines is suggested. The severe environments associated with launch-pad accidents and reentry are discussed, and the safety-analysis steps are briefly described (auth)

Siemens-Schuckertwerke A. G., Erlangen, Germany

171 NUCLEAR ROCKET REACTOR SHIELDING PROBLEMS. Budnick, D. (Siemens-Schuckertwerke AG, Erlangen, Ger.). Atomkernenergie, 10: 443-6(Nov.-Dec. 1965). (In German).

Shielding mass requirements of a nuclear aerospace transporter (manned earth-to-orbit-and-return-vehicle) are treated, considering a 100 Mp thrust nuclear rocket reactor engine (L.B.S.)

Texas Agriculture and Mechanical University, College Station

172 APPROXIMATE ANALYSIS OF THE KIWI TNT EXPERIMENTS. Koehler, W. H. (Texas Agricultural and Mechanical Univ., College Station). Raumfahrtforschung, 10: 14-19(Jan-Mar 1966). (In German)

Several experimental results of the KIWI excursion test are compared to numerical solutions for a point reactor model and to the analytical solution of the Fuchs model (auth)

TRW Systems, Redondo Beach, Calif.

173 (NP-16129) NUCLEAR SPACE MISSIONS A SELECTED BIBLIOGRAPHY. Special Literature Survey No. 9. Velin, R. R.; Magnolia, L. R. (comps.). (TRW Systems, Redondo Beach, Calif.). Sept. 7, 1965. 23p.

A compilation of 220 articles dealing with all aspects of nuclear space missions is presented (M O W)

174 (N-66-16525) FEASIBILITY STUDY OF DIRECT-FLOW GAS CORE REACTOR SYSTEM. Hunter, Henry M.; Degarabedian, P. (TRW Systems, Redondo Beach, Calif.). Jan. 31, 1966. Contract NASw-1166. 316p. (NASA-CR-70013; STL-4393-6003-RO-000) CFSTI \$7.00 cy, \$1.75 mn

The feasibility of a direct-flow gas-core propulsion reactor concept employing a single axial gaseous fuel jet surrounded by a coaxial stream of gaseous hydrogen propellant is investigated. The proposed concept avoids the problems of fuel retention associated with more complex flow fields by collecting the single fuel stream in a scoop located at the discharge end of the reactor where it is cooled, condensed to the liquid phase, and recirculated. The study is primarily concerned with the feasibility of the scoop that collects the hot gaseous fuel at the reactor discharge and, consequently, operates in a severe thermal environment. Computer programs were used to determine the heat loads and mixing between fuel and propellant streams. Various advanced cooling techniques were used to determine the feasibility of cooling the fuel scoop. The propulsion system was analyzed in sufficient depth to uncover critical problem areas and to establish reasonable design and performance conditions for evaluation of system feasibility (auth)

United Aircraft Corp., East Hartford, Conn. Research Laboratories

175 (CONF-660608-13) ABSORPTION OF THERMAL RADIATION IN THE TRANSPARENT WALL OF A NUCLEAR LIGHT BULB ROCKET ENGINE. McLafferty, George H. (United Aircraft Corp., East Hartford, Conn. Research Labs.). Apr. 1966. 18p. (UAR-E63).

From 2nd AIAA Propulsion Joint Specialist Conference, Colorado Springs.

An analytical study was conducted to determine heat deposition rates in the transparent wall of a nuclear light bulb rocket engine. Such an engine is based on the transfer of energy by thermal radiation from gaseous nuclear fuel through a solid transparent wall to seeded hydrogen propellant. The analysis employs measured spectral absorption coefficients of fused silica, a possible wall material, with and without corrections for reactor-induced opacity in the walls. The calculations are carried out for a radiant energy spectrum approaching the walls equal to the black-body spectrum at the edge-of-fuel temperature and for a black-body spectrum corrected for the effects of an oxygen seed between the gaseous nuclear fuel and the transparent wall. Calculations are also made to determine the temperature differences across the transparent wall necessary to remove the energy deposited in the wall. Results of the calculations indicate that the addition of an oxygen seed to modify the heat flux incident on the transparent wall has a large effect on the heat deposition and required temperature gradients in the wall (auth)

176 (D-910091-5) EXPERIMENTAL INVESTIGATION OF THE EFFECT OF PERIPHERAL-WALL INJECTION TECHNIQUE ON TURBULENCE IN AN AIR VORTEX TUBE. McFarlin, David J. (United Aircraft Corp., East Hartford, Conn. Research Labs.). Sept. 1965. Contract NASw-847. 48p.

Experiments were conducted to investigate the effect of the peripheral-wall injection technique used to drive an air vortex on the level of turbulence in the vortex. Two injection configurations were tested in separate 10-in.-dia vortex tubes. In both tubes, a controlled quantity of air was removed through ports located at the centers of the two end walls or was injected through a porous tube located on the centerline of the vortex; air was also removed through perforated plates in the peripheral wall. Hot-wire-anemometer measurements of tangential velocity profiles and root-mean-square velocity fluctuations were made near the peripheral wall at three circumferential stations at one

axial location (the axial midplane). The results indicated that the interior region of low-turbulence flow was larger for a 2144-port configuration than for a single-slot configuration. (auth)

177 (D-910091-7) EXPERIMENTAL INVESTIGATION OF PERIPHERAL-WALL INJECTION TECHNIQUES IN A WATER VORTEX TUBE. Travers, Arthur (United Aircraft Corp., East Hartford, Conn. Research Labs.). Sept. 1965. Contract NASw-847. 50p.

An experimental investigation was conducted to determine the effects of the peripheral-wall injection technique used to drive a water vortex on the structure and thickness of the turbulent mixing region near the peripheral wall and on the flow patterns in the primary-flow region outside the peripheral and end-wall boundary layers. Three 10-in.-dia lucite vortex tubes having three different peripheral-wall injection configurations were tested. In most tests, a controllable quantity of fluid was removed through one or more perforated screens in the peripheral wall and the remainder of the fluid was removed through 0.938-in.-dia thru-flow ports located at the centers of the two end walls. However, a few tests were conducted in which no fluid was removed through the thru-flow ports, instead, fluid was injected through a 1.0-in.-dia porous tube located along the centerline of the vortex tube. Microflash photographs of dye patterns were taken through one of the end walls to observe the characteristics of the turbulent mixing region, and time-exposure photographs of dye patterns were taken through the side wall to observe the characteristics of the primary-flow region. Tangential velocity profiles in the primary-flow region were obtained by means of a photographic particle-trace method using small, neutrally buoyant polystyrene spheres. The results indicate that the volume of low-turbulence flow in the primary-flow region was considerably larger for 2144-port injection configuration than for the single-slot and four-slot injection configurations. (auth)

178 (D-910093-19) ANALYTICAL STUDY OF HYDROGEN TURBOPUMP CYCLES FOR ADVANCED NUCLEAR ROCKETS. McLafferty, G. H.; Michels, H. H.; Latham, T. S.; Roback, R. (United Aircraft Corp., East Hartford, Conn. Research Labs.). Sept. 1965. Contract NASw-847. 80p. CFSTI.

An analytical study is conducted to determine the characteristics of three different turbopump cycles that might be employed to obtain the high engine inlet pressures that are expected in advanced nuclear rockets. The three cycles considered are a topping cycle, in which the power required to drive the pump is obtained by passing all of the pump-exit flow through a turbine before this flow enters the engine, a bleed cycle, in which all of the pump power is obtained by discharging a fraction of the pump-exit flow through a bleed turbine with an expansion pressure ratio of 0.01, and a mixed cycle, in which half of the power to drive the pump is obtained from a primary turbine and half from a bleed turbine. The studies were conducted for turbine inlet temperatures between 1400 and 3800°R, for turbine inlet pressures between 200 and 5000 atm, for pressure drops between the pump exit and the turbine inlet of zero and 50 atm, and for three different combinations of pump and turbine efficiency. The results of the study include the effect of engine inlet pressure on the turbine pressure drop and/or the bleed flow fraction for each cycle. Studies not connected with hydrogen turbopumps are also described. These are an analysis of the approximate temperature distribution in the fuel-containment region of a coaxial-flow gaseous nuclear rocket; a change in form of heavy-gas containment data obtained from NASA Lewis coaxial-flow tests, and an analysis of the heat generation rate in fuel passing through a fuel-injection duct located in the moderator of a gaseous nuclear rocket engine. (auth)

179 (N-67-16013) THEORETICAL INVESTIGATION OF RADIANT HEAT TRANSFER IN THE FUEL REGION OF A GASEOUS NUCLEAR ROCKET ENGINE. Kesten, A. S.; Krascella, N. L. (United Aircraft Corp., East Hartford, Conn.). Jan. 1967. Contract NASw-847. 32p. (NASA-CR-695). CFSTI \$3.00 cy, \$0.65 mn.

A number of different gaseous nuclear rocket engine concepts have been proposed in which energy is transferred from the fuel to the propellant by thermal radiation, for example, the coaxial-flow reactor and the nuclear light bulb reactor. The temperature distribution in the fuel-containment region of such engines is

dependent upon the fuel opacity characteristics. These opacity characteristics can be analytically determined using a heavy-atom model which requires, as a prerequisite, a knowledge of the ionization potentials of the nuclear fuel. To date, two independent theoretical estimates of the first four ionization potentials of uranium have been made. The object of the study was to ascertain the effect of fuel opacity characteristics by using the heavy-atom model and the ionization potentials on the temperature distributions in the fuel-containment region of gaseous nuclear rocket engines. (STAR)

180 (NP-16337) THEORETICAL INVESTIGATION OF RADIANT HEAT TRANSFER IN THE FUEL REGION OF A GASEOUS NUCLEAR ROCKET ENGINE. Report E-910092-9. Kesten, Arthur S.; Krascella, N. L. (United Aircraft Corp., East Hartford, Conn. Research Labs.). Sept. 1966. Contract NASw-847. 28p.

A series of calculations were made to determine temperature distributions in the fuel-containment region of gaseous nuclear rocket engines which are based on the transfer of energy by thermal radiation from the fuel to the propellant. Temperature distributions were determined for two sets of fuel opacities, the opacities in each of these sets were calculated from an analytical heavy-atom model using two recent theoretical estimates of fuel ionization potentials. The temperatures near the centerline of the fuel-containment region were found to be high and relatively insensitive to changes in fuel opacity. (auth)

181 (NP-16785) EXPLORATORY FLOW AND CONTAINMENT EXPERIMENTS IN A DIRECTED-WALL-JET VORTEX TUBE WITH RADIAL OUTFLOW AND MODERATE SUPERIMPOSED AXIAL FLOWS. Johnson, Bruce V. (United Aircraft Corp., East Hartford, Conn. Research Labs.). May 1967. Contract NASw-847. 89p. (F-910091-11).

Exploratory fluid mechanics experiments were performed to obtain information applicable to an open-cycle, vortex-stabilized, gaseous-core nuclear rocket. The containment characteristics of confined radial-outflow vortices with superimposed axial flow were studied to determine whether high average simulated-fuel densities and high ratios of simulated propellant-to-fuel flow rates could be obtained. The experiments concentrated on factors that influence simulated-fuel containment such as simulated-propellant injection methods in which the flow is injected from the peripheral wall of an axial-flow vortex tube with both axial and tangential (circumferential) components of velocity, and simulated-fuel injection methods. The experiments were performed in 10-in.-dia by 30-in.-long vortex tubes. Simulated propellant was injected at the peripheral wall through 600 directed wall jets that could be adjusted to any injection flow angle between the tangential and axial directions. Flow visualization tests were performed using water with dye as a trace fluid. The dye patterns showed that large-scale turbulent mixing occurred between the central region and the peripheral-wall region when the simulated fuel was injected from ducts at the centers of both end walls (radial outflow). Velocity measurements were made using air as the working fluid. These measurements indicated that injection at the peripheral wall with both axial and tangential components of velocity will substantially decrease the average axial velocities in the central region and will create a larger volume within the vortex that is potentially available for containment of fuel. Containment tests to determine the average dwell time of simulated fuel in the vortex tube were performed using a heavy gas to simulate fuel and a light gas to simulate propellant. Compared with the containment times measured with no axial component of injection velocity, improvements in containment time of as much as a factor of three-and-one-half were obtained in this investigation using injection with both axial and tangential components of velocity. The improvements that can be obtained using different fuel injection methods are smaller. However, the maximum containment times that were measured were approximately one to two orders of magnitude less than the value now estimated to be required for an economically practical, open-cycle, gaseous-core nuclear rocket. (auth)

182 (NP-16786) CONTAINMENT EXPERIMENTS IN VORTEX TUBES WITH RADIAL OUTFLOW AND LARGE SUPERIMPOSED AXIAL FLOWS. Kendall, John S.; Mensing, Arthur E.; Johnson, Bruce V. (United Aircraft Corp., East Hartford, Conn. Research Labs.). May 1967. Contract NASw-847. 92p. (F-910091-12).

An experimental investigation was conducted to determine the heavy-gas containment characteristics of radial-outflow vortices for potential application to a vortex-stabilized, open-cycle gaseous nuclear rocket engine. Tests were conducted in a constant-temperature vortex with Reynolds numbers based on the superimposed axial flow up to those expected in a full-scale engine. Air was employed to simulate the seeded H₂ propellant and a

heavy fluorocarbon was used in most tests to simulate the gaseous nuclear fuel. The effects on heavy-gas containment of changes in the vortex tube length-to-diameter ratio, the light-gas injection geometry and area, the ratio of average heavy-gas density to light-gas density, and the density of the heavy gas at injection were studied. The heavy-gas containment parameters obtained were one to two orders of magnitude less than are presently estimated to be required for an economically practical open-cycle engine. The containment parameters varied significantly only with vortex tube length-to-diameter ratio and the ratio of average heavy-gas density to light-gas density. The results of some tests using He injected near the centerline of the vortex indicated that the presence of a light gas in the central region of the vortex has a significant favorable effect on the containment characteristics; these results have potential application to the nuclear light bulb engine. (auth)

183 (NP-16787) SUMMARY OF GASEOUS NUCLEAR ROCKET FLUID MECHANICS RESEARCH CONDUCTED UNDER CONTRACT NASw-847. Clark, James W.; Kendall, John S.; Johnson, Bruce V.; Mensing, Arthur E.; Travers, Arthur (United Aircraft Corp., East Hartford, Conn. Research Labs.). May 1967. Contract NASw-847. 59p. (F-910091-13).

The characteristics of vortex flows were obtained for evaluating the feasibility of two vortex-stabilized gaseous nuclear rocket engine concepts. Most of the fluid mechanics research was directed toward the vortex-stabilized open-cycle concept; the results are also applicable to the closed-cycle nuclear light bulb concept. Both concepts are based on the transfer of energy by thermal radiation from gaseous nuclear fuel contained in a vortex to seeded hydrogen propellant. In the open-cycle engine, propellant is injected at the peripheral wall of the cavity to drive the vortex and then spirals axially around the fuel-containment region toward the exhaust nozzle. Nuclear fuel is injected into the central region of the cavity where it is contained for a period of time by the vortex flow field. In the nuclear light bulb engine, the propellant and vortex regions are separated by an internally cooled transparent wall. Ne coolant is injected tangent to the inner surface of the transparent wall to drive the vortex and to provide a buffer region to isolate the gaseous nuclear fuel from the transparent wall. Results of the fluid mechanics are investigated and interpreted in terms of the requirements of these two engines. Containment tests were conducted using gases having different molecular weights to simulate the gaseous nuclear fuel and either the propellant or the Ne coolant. Flow visualization tests were conducted and flow-field velocity measurements were made using water and air vortices to obtain fundamental information on vortex flow patterns. The principal geometrical parameters investigated in the program were the length-to-diameter ratio of the vortex tube, the geometry of the system used to inject light gas at the peripheral wall, the geometry of the system used to inject heavy gas, the locations and sizes of the ports for removing flow (an annulus at the outer edge of one end wall, ports at the centers of the end walls, and ports at the peripheral wall), and end-wall boundary layer control. The flow conditions tested included Reynolds numbers up to those estimated to be required for full-scale engines. Based on the results of this investigation and concurrent engine design and performance studies, it is concluded that the fuel loss rate in a full-scale, vortex-stabilized open-cycle engine would be too great to permit economical engine operation. The maximum containment parameters measured in the two-component-gas tests were more than an order of magnitude less than the value now estimated to be required for the engine. However, certain types of vortex flows that have been investigated appear to be suitable for the nuclear light bulb engine, and it is recommended that further fluid mechanics research be directed toward this concept. (auth)

184 ABSORPTION OF THERMAL RADIATION ON THE TRANSPARENT WALL OF A NUCLEAR LIGHT BULB ROCKET ENGINE. McLafferty, George H. (United Aircraft Research Labs., East Hartford, Conn.). J. Spacecraft Rockets, 4: 758-61 (June 1967).

An analytical study was conducted to determine heat deposition rates in the transparent wall of a nuclear light bulb rocket engine. Such an engine is based on the transfer of energy by thermal radiation from gaseous nuclear fuel through a solid transparent wall to seeded hydrogen propellant. The analysis employs measured spectral absorption coefficients of fused silica, a possible wall material, with and without corrections for reactor-induced opacity in the walls. The calculations are carried out for a radiant energy spectrum approaching the walls equal to the blackbody spectrum at the edge-of-fuel temperature, and for a blackbody spectrum corrected for the effects of the addition of an oxygen seed to the transparent buffer gas located between the gaseous nuclear fuel and the transparent wall. Calculations are also made to determine the temperature differences across the transparent wall necessary to remove the energy deposited in the wall. The results of the calculations

indicate that the addition of a small percent of oxygen seed will permit absorption of much of the ultraviolet energy that would otherwise be absorbed in the transparent wall, thereby permitting this energy to be convected away by the buffer gas rather than conducted through the relatively low-thermal-conductivity transparent wall. (auth)

185 LIMITATIONS ON GASEOUS NUCLEAR ROCKET I_{sp} DUE TO NOZZLE COOLANT REQUIREMENTS. McLafferty, George H. (United Aircraft Research Labs., East Hartford, Conn.). J. Spacecraft Rockets, 3: 1515-22 (Oct 1966).

An analysis was conducted to determine approximate limitations on the specific impulse (I_{sp}) of advanced nuclear rocket engines due to hydrogen transpiration coolant flows in the exhaust nozzle. Included in the investigation were analyses to determine the effects of changes in the following: nozzle stagnation pressure, the enthalpy rise of the transpiration coolant fluid, the Stanton number reduction due to transpiration cooling, the technique employed for calculating radiant heat transfer, and the amount of mixing between the transpiration coolant flow and the primary flow. The results indicate that coolant flow requirements will be governed primarily by convective heat transfer at low values of I_{sp} and by radiant heat transfer at high values of I_{sp} . The latter appears to limit the maximum I_{sp} of a hydrogen-propellant nuclear rocket engine to values between approximately 2500 and 5000 sec.

Westinghouse Electric Corporation,
Pittsburgh, Penna.

186 NEW CONTROL TECHNIQUES FOR NERVA REACTORS. Kirschbaum, H. S.; Morris, W. R.; Hohmann, G. L. (Westinghouse Electric Corp., Pittsburgh). IEEE (Inst. Elec. Electron. Eng.), Trans. Nucl. Sci., NS-13: No. 1, 670-5 (Feb. 1966).

The control systems that were used to test the early KIWI and NRX reactors are briefly discussed, together with improvements in the control systems. (D.C.W.)

187 RADIATION ENVIRONMENT ABOUT THE NERVA REACTORS. Brooks, E. H.; Woodsum, H. C.; Capo, M. A. (Westinghouse Electric Corp., Pittsburgh). IEEE (Inst. Elec. Electron. Eng.), Trans. Nucl. Sci., NS-13: No. 1, 663-9 (Feb. 1966).

Some measurements of gamma dose rates and neutron flux distributions that were made during the testing of the NRX-A2 and NRX-A3 reactors are summarized. The experimental results are compared with theoretical predictions. (D.C.W.)

188 NERVA NUCLEAR REACTOR INSTRUMENTATION. Mallick, F. S.; Ramp, R. L.; Gilmour, G. A. (Westinghouse Electric Corp., Pittsburgh). IEEE (Inst. Elec. Electron. Eng.), Trans. Nucl. Sci., NS-13: No. 1, 685-91 (Feb. 1966).

The instrumentation problems associated with the development of the reactor are discussed, together with the extent of the solution of the problems. Vibration, displacement, and pressure transducers; strain gages; high-temperature thermocouples; neutron detectors; and calorimeters are discussed. (D.C.W.)

Westinghouse Electric Corporation,
Pittsburgh, Penna. Astronuclear Laboratory

189 (CONF-651101-84) NERVA REACTOR DEVELOPMENT STATUS. Esselman, W. H.; Arnold, W. H. (Westinghouse Electric Corp., Pittsburgh Pa. Astronuclear Lab.). Nov. 1965. Contract SNP-1. 27p. Dep. mn. CFSTI \$2.00 cy, \$0.50 mn.

From 13th Conference on Remote Systems Technology, Washington, D. C.

The Project Rover Reactor Development Program progress is summarized from its beginning in 1955. The development, testing, and evaluation of the KIWI, NRX, and NERVA reactors are described. (H.D.R.)

190 (CONF-660206, pp 285-314) NERVA REACTOR TRANSFER-FUNCTION MEASUREMENTS WITH CROSS-CORRELATION TECHNIQUES. Wasserman, A. A.; Steiner, G. H.; Bodenschatz, C. A.; Honka, E. K. (Westinghouse Electric Corp., Pittsburgh, Pa. Astronuclear Lab.).

System transfer functions of several reactor prototypes for the Nuclear Engine for Rocket Vehicle Application (NERVA), were measured by means of noise techniques. Data were analyzed with digital cross-correlation data-processing codes. System transfer functions were derived from measurements made during the NERVA NRX-A2 test series. Measurements were made with pseudorandom signals with noise-level amplitudes which were inserted into the reactor system during steady state holds. Transfer function test data from the NRX-A3 series were analyzed for the EP-II-FC facility checkout and the EP-IV full power reactor test. Binary pseudorandom signals generated by feedback shift register were applied to turbo-pump speed demand and/or power demand. The gain and phase of each transfer function were computed from the power spectral density of selected input signal and cross spectral density of input and output signals. (M.L.S.)

191 THE TESTING OF NRX/EST AND NRX-A5. Davison, P. W. (Westinghouse Electric Corp., Pittsburgh). New York, American Institute of Aeronautics and Astronautics, 1966. Preprint No. 66-1004, 7p., \$1.50. (CONF-661124-1). DTIC. From 3rd AIAA Annual Meeting, Boston.

The primary objective of the NRX/EST test series was the testing of a "breadboard" nuclear rocket engine system using a hot bleed port nozzle. A secondary objective was a reactor duration test. The major accomplishments were: the demonstration of "bootstrap" start-up capability over a wide range of operating conditions to intermediate power and full power; the acquisition of data to validate and further develop analytical models of the engine control system; and operation at or above 3800°R chamber temperature for 27 minutes. The primary objective of the NRX-A5 test series was to determine the reactor duration capability. The major secondary objectives were to demonstrate the feasibility of a "no flux loop" temperature controller and a fixed control drum start-up from low to high power, and to measure more precisely the radioactive effluent discharged from the reactor. The total operating time at or above 3800°R chamber temperature and 71.3 lb/sec propellant flow rate was 29.4 minutes. During both full power operations, in-core temperature measurements were used to directly control the reactor power, the nuclear power instrumentation was used only for monitoring and safety (scram) functions. For the second power test, an engine-type neutronics system was used with special detectors located near the dome end of the pressure vessel and eight-decade (30 watts to 3,000 megawatts) log amplifiers. A fixed control drum start-up, i. e., power controlled by a programmed propellant flow rate ramp, was performed from 30 kilowatts to 720 megawatts for the second power test. Smoke from JATO units exhausted vertically about 200 feet from the test assembly was used successfully to mark the effluent cloud. (auth)

192 (N-66-19533) TRANSIENT TWO-PHASE HEAT TRANSFER AND FLOW CHARACTERISTICS OF LIQUID HYDROGEN. Campi, F. A.; Chi, J. W. H.; De Zubay, E. A.; Holmgren, J. D.; Vetere, A. M. (Westinghouse Electric Corp., Pittsburgh, Pa. Astronuclear Lab.). Apr. 1963. 89p. (NASA-CR-71087; WANL-TNR-102). CFSTI \$3.00 cy, \$0.65 mn.

The initial phase of a program designed to evaluate transient two-phase heat transfer and flow characteristics of hydrogen as an integral part of the NERVA reactor requirement are summarized. A hydrogen facility and cryogenic laboratory was built, and experiments were performed to obtain the desired data. The experimental program included studies of single phase heat transfer, two-phase flow, and forced convection transient boiling heat transfer. The investigations were made with cold gaseous and liquid hydrogen flowing through horizontal test sections over a range of conditions. Cool-down temperature, cool-down time, single phase heat transfer coefficients, transient two-phase flow characteristics, and two-phase heat transfer coefficients are presented. It was shown that, in the film boiling and transitional regimes, thermodynamic equilibrium cannot exist between the vapor and the liquid. The mechanisms of two-phase flow during cool-down was discussed in detail, and a two-phase flow model has been postulated. (auth)

193 (WANL-TME-537(Rev.1)) REVISED FISSION PRODUCT INVENTORY PROGRAM (FPIP-REV). Brown, W. S.; Call, D. W. (Westinghouse Electric Corp., Pittsburgh, Pa. Astronuclear Lab.). May 1967. 73p. Dep. CFSTI.

FPIP-REV calculates the time behavior of 254 fission product nuclides formed by fissioning of ²³⁵U resulting from a specified

reactor operating history. The operating history can consist of as many as six separate operating periods, each at an arbitrary power level. The activity is calculated for each nuclide and summed for the total inventory. The program calculates the γ and β radiation energy source strengths (MeV/sec) in each of seven γ and five β energy groups versus decay time after final shutdown. Also, for each decay time, the integrated γ and β source strengths (MeV) per group are determined over a specified time span immediately subsequent to that decay time. The program has been used within the ROVER Program to predict fission product inventories and source strengths associated with operation of the NERVA reactor. Data used in the program library for the physical constants of the fission product nuclides, chain branching ratios, etc., are the same as those values used by USNRDL. Five limitations of the program are listed. (J.C.W.)

194 (WANL-TME-1153) EFFECTIVENESS OF VERTICAL SHIELDS IN A CLUSTER OF THREE NERVA II MODULES. Ricks, L. O. (Westinghouse Electric Corp., Pittsburgh, Pa. Astronuclear Lab.). Apr. 1965. Contract SNP-1 44p. Dep. mn. CFSTI \$2.00 cy, \$0.50 mn.

The two locations for shields considered here are in the regions between the top shadow shield and reflector and around the reflector. Only one material, lithium hydride-steel, was considered for the top shield, three materials were considered for the extension and side shields. These three materials were lead, steel, and lithium hydride-steel. (M.O.W.)

195 (WANL-TME-1254) NON-NUCLEAR EVALUATION TESTING OF STRAIN GAGES BONDED WITH CERAMIC CEMENT. Kalning, L. (Westinghouse Electric Corp., Pittsburgh, Pa. Astronuclear Lab.). Aug. 27, 1965. Contract SNP-1. 62p. Dep. mn. CFSTI \$3.00 cy, \$0.65 mn.

The feasibility of using ceramic bonded strain gages on NERVA reactor components was investigated. The goal of this investigation was to develop a strain gage technique which would offer improved accuracy and have smaller physical dimensions than the Microdot weldable gages presently being used for diagnostic purposes on NRX reactors. In addition, a strain gage technique is needed for those reactor components such as the beryllium control drums where spot welding of the Microdot gages is not possible. Non-nuclear evaluation tests were conducted on strain gages bonded with ceramic cement to constant strain beams, tie rods, a control drum, and lateral support springs. Both static and dynamic tests were conducted over a temperature range of -320 to +600°F under loads simulating expected NERVA conditions. The results of this investigation revealed that the ceramic bonded strain gages are in many respects superior to the Microdot weldable gages. However, more development is needed to improve lead routing and strain gage connection techniques. In addition, it was demonstrated that present moisture-proofing techniques are inadequate for strain gage installations on certain reactor components after they have been subjected to cryogenic temperatures and exposed to room air. (auth)

196 (WANL-TME-1465) DESIGN AND DEVELOPMENT OF THE ALL-WELDED-AND-BRAZED INSTRUMENTATION PORTS FOR NERVA REACTORS. Kavalkovich, W. (Westinghouse Electric Corp., Pittsburgh, Pa. Astronuclear Lab.). July 7, 1966. Contract SNP-1 18p. Dep. mn. CFSTI \$1.00 cy, \$0.50 mn.

The design and development of all-welded-and-brazed instrumentation ports for NERVA reactors are discussed. The instrumentation ports permit passage of bundles of instrumentation leads through the pressure vessel wall. Brazing and welding processes are utilized in the port assembly to provide a leak-tight seal between the stainless steel-sheathed instrumentation leads and the reactor's Al pressure vessel. Comprehensive testing demonstrated that the subject assembly remains leak tight (leakage rate less than 10^{-6} standard cc H₂/sec) through resonant vibrations, hydraulic and structural shock loads and during extreme thermal cycles. (auth)

197 (WANL-TME-1466) SECOND STATUS REPORT SHIELDING STANDARD DESIGN METHOD. (Westinghouse Electric Corp., Pittsburgh, Pa. Astronuclear Lab.). Mar. 1, 1967. Contract SNP-1. 91p. Dep. CFSTI.

The Shielding Standard Design Method is employed by WANL to perform NERVA radiation and shield analyses and design. This method, designated Shielding Standard Design Method II (SSDM-II), is the second generation of methods which has evolved from evaluating comparisons of calculated versus experimental radiation environment data. SSDM II employs three widely used analytical techniques, Monte Carlo, S_N transport, and point kernel. Monte Carlo Program 18-0 is specifically used to calculate gamma ray heating within the pressure vessel. The two dimensional S_N trans-

port code, TDC, generate neutron fluxes by group in an r,z geometry. Point kernel Program 14-0 is used to compute external radiation environment. Many subsidiary linked programs are also employed to generate input data and process output data. Extensive comparisons of SSDM II calculated data with NRX experimental data and other applicable experimental data are presented. The experimental data include internal and external reactor gamma ray dose rates, external fast neutron ($E > 2.9$ MeV) and thermal neutron environment, and liquid H_2 propellant heating data. A continuous effort is in progress to improve and to more fully automate the SSDM II System. These improvements, which are described in detail include: (1) replacing the TDC transport code with the DDK two dimensional transport code for more accurate calculation of neutron fluxes, and (2) replacing the 14-0 point kernel code with the WANL KAP point kernel code. Two unique neutron-photon S_N transport code system (for one and two dimensional analysis) are being developed. Application of the S_N transport to photon transport analysis is expected to facilitate radiation analysis of reactor-shield systems. (auth)

198 (WANL-TME-1475) NRX/EST TRANSFER FUNCTION MEASUREMENTS BY CONTROL DRUM PERTURBATION AND COMPARISON WITH COMMON ANALYSIS MODEL PREDICTIONS. Steiner, G. H. (Westinghouse Electric Corp., Pittsburgh, Pa. Astronuclear Lab.). Nov. 1966. Contract SNP-1. 136p. Dep. CFSTI.

Transfer function measurement tests were performed on the NRX/EST nuclear rocket test system. The purpose of these tests was to obtain quantitative information on the dynamic characteristics of the basic system without controllers, to assess the advantages and disadvantages of three different methods of transfer function measurement, and to permit comparison of the response of the common analysis model used for system design and prediction with experimental results. Cross-correlation methods of transfer function measurements are compared with sinusoidal and step response results. Transfer functions were also predicted by the modified CAM-IIC computer model and were compared with experiment results. (M L S)

199 (WANL-TME-1478) PARA-HYDROGEN CODES. Pierce, B. L. (Westinghouse Electric Corp., Pittsburgh, Pa. Astronuclear Lab.). Aug 15, 1966. Contract SNP-1. 60p. DTIC.

FORTAN IV para-hydrogen property programs, which are modifications of Los Alamos Scientific Laboratory TAB Code, are described. Changes were made to the TAB Code to reduce computer storage requirements and to obtain continuous property values. Instructions in the use of the programs are provided. Tabulation of property values for para-hydrogen in the temperature range from 36 to 5000°R and pressure range from 14.7 to 2000 psia are included. (auth)

200 (WANL-TME-1610) FRACTURE TOUGHNESS OF BERYLLIUM. Harrod, D. L.; Hengstenberg, T. F.; Manjoine, M. J. (Westinghouse Electric Corp., Pittsburgh, Pa. Astronuclear Lab.). June 1967. Subcontract NP-1. 40p. Dep. CFSTI.

The opening mode plane strain fracture toughness of vacuum hot pressed S-200 grade Be was determined in the temperature range -320°F to 500°F. Two different test specimen designs were employed, and a number of other variables were investigated to a limited extent. The temperature dependence of fracture toughness was found to be approximately linear between -320°F and room temperature. Fracture toughness was nearly isotropic, and was not dependent upon loading rate for crosshead speeds up to 2 in./min. Heat treatments were found to have a pronounced effect on fracture toughness. Fractographic observations failed to reveal any correlation between fracture toughness and the various test variables, including the response to heat treatment and the effect of test temperature. (auth)

201 (WANL-TME-1619) CRYOGENIC AND AMBIENT TENSILE AND COMPRESSION PROPERTIES OF HOT-PRESSED BLOCK BERYLLIUM. Kesterson, R. L. (Westinghouse Electric Corp., Pittsburgh, Pa. Astronuclear Lab.). June 1967. 45p. Dep. CFSTI.

The tensile and compression properties of S-200 grade Be were investigated in the temperature range of +70°F to -320°F. This hot-pressed block material is presently being used for both sector and ring types of NERVA outer reflectors. The objectives of this investigation included: statistical comparison of the mechanical properties of ring and sector material; statistical comparison of the lot to lot variation in the mechanical properties of hot-pressed Be; statistical study of the testing temperature effect on the mechanical properties; and study of the notched tensile behavior. The experiment was designed such that a sta-

tistical data analysis would produce an optimum amount of information. The results from the analysis were used to develop stress-strain curves with 75%, 90%, 95%, and 99% tolerance limits and with a 90% confidence factor. The results indicate that on a statistical basis no real difference exists between the cryogenic mechanical properties of the ring and block pressings. However, there is less variance in properties of ring-type pressings, and thus this type of Be pressing is favored. (auth)

202 ANALOG SIMULATION OF AMBIENT-GAS EMERGENCY COOLING OF NERVA REACTOR SYSTEMS. Rovnak, J. A. (Westinghouse Astronuclear Lab., Pittsburgh). Trans. Amer. Nucl. Soc., 9: 326-7 (Oct.-Nov. 1966).

203 AN ANALYSIS FOR CORRELATING GROUND DESTRUCT TESTS WITH IN-FLIGHT DESTRUCT OF NUCLEAR ROCKETS. Hargrove, H. G.; Trammell, M. R. (Westinghouse Astronuclear Lab., Pittsburgh). Trans. Amer. Nucl. Soc., 8: 567-8 (Nov. 1965).

204 APPLICATION OF S_N -TRANSPORT MULTIGROUP ANGULAR-FLUX DATA TO PREDICT NERVA RADIATION ENVIRONMENTS. Disney, R. K.; Soltesz, R. G.; Romesburg, H. C. (Westinghouse Astronuclear Lab., Pittsburgh). Trans. Amer. Nucl. Soc., 9: 332-3 (Oct.-Nov. 1966).

205 CALORIMETRIC RADIATION HEATING RATE MEASUREMENTS AND ANALYSIS FOR NERVA REACTORS. Capo, M. A.; Gilmour, G. A. (Westinghouse Astronuclear Lab., Pittsburgh). Trans. Amer. Nucl. Soc., 9: 331-2 (Oct.-Nov. 1966).

206 COMPARISON OF ANALYTICAL AND EXPERIMENTAL OPERATING REACTIVITY OF NERVA REACTORS. Ortenberg, L. I.; Mowery, A. L.; Hill, D. J. (Westinghouse Astronuclear Lab., Pittsburgh). Trans. Amer. Nucl. Soc., 8: 553-4 (Nov. 1965).

207 COMPARISON OF ANALYTICAL AND EXPERIMENTAL POWER DISTRIBUTION OF NERVA REACTORS. Doncals, R.; McCutchan, D. A.; Ortenberg, L.; Ravets, J. (Westinghouse Astronuclear Lab., Pittsburgh). Trans. Amer. Nucl. Soc., 8: 554-5 (Nov. 1965).

208 COMPARISON OF MEASURED AND CALCULATED INTERNAL RADIATION ENVIRONMENT FOR THE NRX REACTORS. Nassano, R. N. (Westinghouse Astronuclear Lab., Pittsburgh). Trans. Amer. Nucl. Soc., 9: 331 (Oct.-Nov. 1966).

209 DESIGN OF PSEUDO-RANDOM-NOISE EXPERIMENTS FOR NERVA TESTS. Steiner, G. H. (Westinghouse Astronuclear Lab., Pittsburgh); James, Leslie R.; Uhrig, R. E. Trans. Amer. Nucl. Soc., 9: 328-9 (Oct.-Nov. 1966).

210 THE DESIGN AND ANALYSIS OF A POISSON SYSTEM FOR SAFE SHIPPING THE NERVA REACTOR. Speis, T. P.; Ortenberg, L. I.; Mowery, A. I. (Westinghouse Astronuclear Lab., Pittsburgh). Trans. Amer. Nucl. Soc., 8: 568-9 (Nov. 1965).

211 THE DETERMINATION OF AIRBORNE RADIOACTIVITY DURING NERVA REACTOR TESTING. Rymer, G. T.; Henninger, W. A.; Grandy, G. L. (Westinghouse Astronuclear Lab., Pittsburgh). Trans. Amer. Nucl. Soc., 10: 1-2 (June 1967). From 13th Annual Meeting of the American Nuclear Society, San Diego, Calif., June 11-15, 1967. See CONF-670602.

212 FCX INITIAL CRITICALITY EXPERIMENTS AND ANALYSIS. Freidhof, W. E.; Barksdale, C. E.; Mowery, A. L.; Bevard, D. G. (Westinghouse Astronuclear Lab., Pittsburgh). Trans. Amer. Nucl. Soc., 10: 10-11 (June 1967). From 13th Annual Meeting of the American Nuclear Society, San Diego, Calif., June 11-15, 1967. See CONF-670602.

213 IN-CORE TEMPERATURE CONTROL OF NRX REACTORS. Elmiger, R. A. (Westinghouse Astronuclear Lab., Pittsburgh). J. Spacecraft Rockets, 3: 262-3 (Feb. 1966).

The design and performance of an in-core temperature control system for the NRX reactors are discussed. (B G D.)

214 INTEGRAL AND DIFFERENTIAL REACTIVITY COEFFICIENTS. Ravets, J. M.; Spush, P. J.; Bevard, D. G. (Westinghouse Astronuclear Lab., Pittsburgh). Trans. Amer. Nucl. Soc., 10: 200-1 (June 1967).

From 13th Annual Meeting of the American Nuclear Society, San Diego, Calif., June 11-15, 1967. See CONF-670602.

215 LIMITERS IN NERVA REACTOR CONTROL. Hohmann, Garold L.; Walsh, Joseph M.; Honka, Eric K. (Westinghouse Astronuclear Lab., Pittsburgh). Trans. Amer. Nucl. Soc., 9: 152 (June 1966).

216 NERVA REACTOR CONTROL. Kirschbaum, H. S.; Morris, W. R. (Westinghouse Astronuclear Lab., Pittsburgh). Trans. Amer. Nucl. Soc., 8: 555 (Nov. 1965).

217 NERVA REACTOR EXPERIMENT (NRX) REACTOR TESTING. Davison, P. W. (Westinghouse Astronuclear Lab., Pittsburgh); Ney, E. J.; Neal, P. E. Trans. Amer. Nucl. Soc., 8: 551-2 (Nov. 1965).

218 NRX/EST REACTOR TRANSFER FUNCTIONS PART I POWER-TO-TEMPERATURE TRANSFER FUNCTIONS. Bodenschatz, C. A.; James, L. R.; Steiner, G. H.; Wasserman, A. A. (Westinghouse Astronuclear Lab., Pittsburgh). Trans. Amer. Nucl. Soc., 9: 327-8 (Oct.-Nov. 1966).

219 NRX/EST NUCLEAR ROCKET REACTOR TRANSFER FUNCTIONS PART II PRESSURE-TO-PRESSURE TRANSFER FUNCTIONS. James, L. R. (Westinghouse Astronuclear Lab., Pittsburgh); Steiner, G. H.; Bodenschatz, C. A.; Uhrig, R. E. Trans. Amer. Nucl. Soc., 9: 328 (Oct.-Nov. 1966).

220 ONE-DIMENSIONAL CALCULATIONS OF NERVA REACTOR CONTROL SPANS. Stefanko, J.; Mowery, A. (Westinghouse Astronuclear Lab., Pittsburgh). Trans. Amer. Nucl. Soc., 10: 201-2 (June 1967).

From 13th Annual Meeting of the American Nuclear Society, San Diego, Calif., June 11-15, 1967. See CONF-670602.

221 PLUM BROOK'S CRYOGENIC IRRADIATION TEST FACILITY. Coombe, John R. (Westinghouse Astronuclear Lab., Large, Pa.). Cryog. Eng. News, 2: No. 6, 16-17; 20-2 (June 1967).

Experimental apparatus and its use for cryogenic temperature effect studies on the Nuclear Engine Rocket for a Vehicle Application (NERVA) reactors in the NASA Plum Brook Reactor Facility are described. The Horizontal Through Hole No. 1 (HT-1) which serves as the experimental access to the reactor core is discussed. The water-cooled facility was used to test resistance temperature transducers, strain gages, linear displacement transducers, mechanical components, pressure transducers, accelerometers, and materials for the NERVA program. Instrumentation and materials tests are to be conducted in the cryogenic loop at maximum nominal environmental conditions of 3×10^{18} nvt E > 1 MeV, and 4.8 watts per gram at gas steam temperatures of 50°R (D C C).

222 POST-TEST ANALOG COMPUTER ANALYSES OF THE NRX/FST NUCLEAR SUBSYSTEM. Goldberg, S. (Westinghouse Astronuclear Lab., Pittsburgh). Trans. Amer. Nucl. Soc., 9: 326 (Oct.-Nov. 1966).

223 A SIMPLE TECHNIQUE FOR ESTIMATION OF THE REACTIVITY WORTH OF STRUCTURES EXTERNAL TO A NERVA REACTOR. Hill, D. J.; Ortenberg, L. I.; McCutchan, D. A. (Westinghouse Astronuclear Lab., Pittsburgh). Trans. Amer. Nucl. Soc., 10: 9-10 (June 1967).

From 13th Annual Meeting of the American Nuclear Society, San Diego, Calif., June 11-15, 1967. See CONF-670602.

Westinghouse Electric Corporation, Pittsburgh, Penna. Atomic Power Division

224 (WCAP-2993) FEASIBILITY OF A CHEMICAL POISON LOOP SYSTEM. Final Report. Eanes, W. F.; Fultonberg, D. N.; Rosal, E. R.; Fletcher, W. D.; Loving, J. J. (Westinghouse Electric Corp., Pittsburgh, Pa. Atomic Power Div.). Sept. 1966. Contract NAS3-5215. 75p. (NASA-CR-72105).

The final experiments performed with the Laboratory Version of the Chemical Poison Loop System (CPLS) are described and the results are analyzed. An overall discussion of the feasibility of using a CPLS to control the reactivity of a rocket reactor is contained, wherein it is concluded that the system should be hydraulically and thermally feasible. However, certain chemical instability problems which were not resolved in the work performed make overall feasibility marginal. (auth)

Miscellaneous

225 CALCULATION OF INTERACTIONS BETWEEN CLUSTERED NERVA REACTORS. Mowery, Alfred L. Jr.; Romesburg, H. C. pp 64-76 of Coupled Reactor Kinetics, Chezem, C. G.; Koehler, W. H. (eds.). College Station, Tex., Texas A and M Press, 1967.

From American Nuclear Society, Coupled Reactor Kinetics Conference, College Station, Tex., Jan. 23-24, 1967. See CONF-670107.

Neutronic couplings between NERVA reactors are discussed. Efficiencies of these coupled cores are calculated; results are discussed. The shell-source technique and iterated fission probability methods for efficiency calculations are compared. 6 references. (M.L.S.)

226 GASEOUS NUCLEAR ROCKET. Rom, Frank E. (to National Aeronautics and Space Administration). U. S. Patent 3,202,582. Aug. 24, 1965. Filed Aug. 28, 1961.

Design of a gaseous nuclear rocket engine is described that has an extremely high working fluid operating temperature, that has a thermal radiation absorption blanket around the fissioning uranium gas, and that has a higher specific impulse than that obtainable with solid fuel element nuclear reactors. One or more streams of a working fluid are introduced concentrically adjacent to a gaseous fissile material in a heating chamber or cell. Introduction of the fluid in this manner permits transfer of heat by radiation from the fissioning gaseous material and reduces the mixing of the working fluid with the gaseous fissioning stream to a minimum, thus increasing the residence time of the fissile material relative to the working fluid to conserve fuel. The proposed rocket propulsion system provides for increasing payload weights while maintaining a constant gross weight. (B L M.)

227 GASEOUS VORTEX FOR A ROCKET MOTOR. Rom, Frank E. (to U. S. Atomic Energy Commission). U. S. Patent 3,270,496. Sept. 6, 1966.

A gaseous nuclear rocket propulsion system in which propellant and gaseous fuel are mixed with a resulting gaseous fission vortex being formed in the combustion chamber is described. The propellant passes through this vortex obtaining a high specific impulse as it is exhausted through a rocket nozzle. (auth)

228 NUCLEAR PROPULSION OF SPACE ENGINES. Spincourt, Jacques. Sci. Progr.-Nature, No. 3369, 26-8 (Jan. 1966). (In French).

The Kiwi experiments on the advantages of solid-core and gaseous-core reactors for space propulsion are briefly indicated. (J.S.R.)

229 NUCLEAR SPACE PROGRAM ORGANIZATION AND PLANS. Finger, Harold B. pp 163-84 of Proceedings of the 1965 Conference, Atomic Industrial Forum, Inc., Washington, D. C. McCluskey, Robert J. (ed.). New York, Atomic Industrial Forum, 1966.

The major points that define the organization under which space nuclear systems developments are being carried out are presented. Progress and planning are outlined for various propulsion and power systems, including the nuclear rocket program, nuclear electric systems, and isotope power systems. (H D R.)

230 REACTOR PHYSICS CALCULATIONS FOR THE GASEOUS CORE CAVITY REACTOR. Kaufman, R. M.; Osborn, W. F. Jr.; Simmons, J. R.; Roth, E. B. Allison Res. Eng., 8: 11-18 (1965).

A series of reactor physics calculations were performed for a gaseous-core cavity reactor using advanced transport codes in order to determine the critical mass of fuel re-

quired in the cavity and its variation with temperature, size cavity and moderator-reflector materials. The critical mass calculations are fundamental to questions of feasibility from a structural and control standpoint (L.B.S.)

231 SAFETY AND RADIATION PROTECTION PROBLEMS OF NUCLEAR POWER SOURCES USED IN SPACE RESEARCH. Makra, Zsigmond. *Atomtech. Tajek.*, 9: 445-52(1966). (In Hungarian).

Radiation protection problems arising from the application of nuclear power sources for space research may be divided in three broad problems: protection of the payload against the radiation from the nuclear power system, protection of the environment against radiation, considering primarily the operating and maintenance personnel, and prevention of the contamination of the environment. Shielding against cosmic radiation represents an additional problem. Contamination may arise as the result of normal operation and as the consequence of an accident. Under normal operation, medium and high-power reactors release considerable amount of fission products. Accidents could have serious consequences. If they occur during or shortly after the launch or as the result of the prompt critical condition when suddenly immersed in water when the space reactor falls into the ocean, the contamination problem is relatively minor but after extended operation, the system may contain a large store of radionuclides. This might be minimized by specifying an orbiting time in space of 10 to 15 half-lives. The chief problem is presented by maintenance operations of nuclear systems after extending operation, specially designed remotely controlled manipulators, more complex than those used in hot cells, must be provided. (TTT)

232 SATURN NUCLEAR STAGE SEEN POSSIBLE IN '75. David, Heather M. *Technol. Week*, 19: 118; 121-3(Nov. 28, 1966).

Tests of two Phoebus reactors and two experimental engines (XE) are to be carried out by 1968. The nuclear third stage for the Saturn V launch vehicle should be flown in 1975. Design analysis and systems analysis are under way on the flight NERVA. Progress has been made with one of the longest-leadtime items — the engine test facility or the Nuclear Rocket Development Station (NRDS) in Nevada. Dynamic tests of the stages would be at NASA's Marshall Space Flight Center, with engine testing done at Jackass Flats, Nevada. Tests must be completed at extending the duration capability, the temperature capability and power density of the reactor, and proving out the flight experimental engine. (J.C.W.)

233 SCIENCE AND ROCKET-NUCLEAR WEAPONS. Anureev, I. I. pp 61-110 of *Atom i Oruzhie*, Moscow, Publishing House of the USSR Ministry of Defence, 1964. (In Russian).

After reviewing the classical physical theory and the great change in concepts caused by Einstein's theory of relativity, the most important milestones of modern physics are recalled briefly. In the discussion of the importance of the discovery of nuclear fission, the tremendous amount of energy that became available through the fission and fusion of nuclei is emphasized. Use of these energy sources for military purposes is reviewed, mentioning that future applications will hopefully provide the means to carry out interplanetary and interstellar space flights. In reviewing the development of aerodynamics and rocket dynamics, the contributions of Tsiolkovski and Meshcherski to the technology of modern rocketry are underlined. This science depends to a great extent on further development of the materials science, propellant chemistry and refractories. Mathematics played the same role for rocket technology as earlier for artillery. The military problems involved in the use of atomic and thermonuclear weapons are examined, mentioning the fallout problem, and the friction-induced heat during the flight of rockets. Ballistic and other types of missiles are considered from the operational viewpoint. The Soviet and US satellite programs are compared. (TTT)

234 A SUMMARY OF EXPOSURES TO THE OFF-SITE POPULATION AS A RESULT OF NUCLEAR REACTOR TESTS CONDUCTED AT THE NUCLEAR ROCKET DEVELOPMENT STATION DURING 1965. Oakley, Donald T. 9p (CONF-660621-16) ORAU Gmelin, AED-CONF-66-193-11

From Health Physics Society, 11th Annual Meeting, Houston, Tex.

A summary of whole body and thyroid exposures resulting from five nuclear reactor experiments conducted at NRDS during 1965 is presented. The exposures are compared with protection standards and it is shown that the exposures are small compared to the standards. (auth)

235 VORTEX ROCKET REACTOR. Colgate, Stirling A. (to U. S. Atomic Energy Commission). U. S. Patent 3,307,357. Mar. 7, 1967.

A fission reactor for rocket propulsion and a method for energizing a propellant are described. The fission reactor defines a generally cylindrical cavity into which a preheated propellant is tangentially injected and isothermally expanded under constant angular momentum conditions by radiative heat transfer from the reactor walls. The propellant traverses the cavity with a vortex motion accompanied by a continuous increase in rotational kinetic energy which is transformed into axial energy of high specific impulse in the exhaust nozzle. (auth)

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London, Central Library, Acton
London, National Reference Library
London, Science Museum Library, South Kensington
Manchester, Central Library
Newcastle upon Tyne, Central Library
Nottingham, Central Library
Sheffield, Central Library

URUGUAY

Montevideo, Comisión Nacional de Energia Atomica

VENEZUELA

Caracas, Instituto Venezolano de Investigaciones Cientificas

VIET-NAM

Saigon, Atomic Energy Office

YUGOSLAVIA

Belgrade, Federal Commission for Nuclear Energy

In International Agencies

AUSTRIA

Vienna, International Atomic Energy Agency

BELGIUM

Brussels, La Bibliotheque EURATOM

FRANCE

Paris, European Nuclear Energy Agency, O E C D

ITALY

Ispra, EURATOM Research Center

SWITZERLAND

Geneva, United Nations Library