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UNITED STATES ATOMIC ENERGY COMMISSION

TID-3561(Rev. 4)

SYSTEMS FOR NUCLEAR AUXILIARY POWER (SNAP)

A Literature Search

Compiled by
Henry D. Raleigh

June 1964

Division of Technical Information

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ABSTRACT

Included are 324 references to publications on the SNAP program and related nuclear-powered generators. The references cover the period January 1956 through April 15, 1964. Author and report number indexes are included.

INTRODUCTION

SNAP is the AEC's program for the development of compact, light-weight, reliable atomic electric power packages for space, sea and land uses. The SNAP numbering system uses odd numbers to identify devices fueled by radioisotopes and even numbers to designate devices employing reactors.

The radioisotope-fueled generator program was initiated in 1956 by the Martin Company. The SNAP-1 program objective was originally the development of a cerium 144-fueled, 500 watt(e), mercury turbogenerator device with a 60-day lifetime. Subsequently this program was changed to use thermoelectric conversion to produce 60 watts(e) continuously for one year.

The first successful demonstration of thermoelectric conversion was in January, 1959, when the SNAP-3 proof-of-principal device was introduced by President Eisenhower as the "atomic battery." SNAP-3 produced 2.5 watts(e) using a half charge of polonium 210 fuel.

Five prototype strontium 90-fueled units developed for the Coast Guard and the Navy for use in coastal navigation aids and automatic weather stations are SNAP-7A, B, C, D and E. SNAP-7A, 7C and 7E are 5 watt(e) systems, and 7B and 7D are 30 watt(e) systems.

SNAP-9A is being developed for use in the TRANSIT navigational satellites. It is a plutonium 238-fueled thermoelectric generator with a design lifetime of 5 to 10 years.

Generators intended for use in the NASA Project Surveyor unmanned soft lunar landing program are SNAP-11 and SNAP-13. SNAP-11 is curium 242-fueled and will provide 18.6 watts(e) for 90 days. SNAP-13 is being developed as an alternate unit for SNAP-11 and is a low-powered cesium-vapor thermionic generator.

Development work on a space reactor system designated SNAP-2 was initiated in 1956 by Atomics International. SNAP-2 is a three kilowatt(e) unit with mercury vapor turbo-generator equipment. Subsequently work on two additional units based on the metal hydride reactor technology have been started. SNAP-8 is a 30 kilowatt(e) propulsive power unit and SNAP-10A is a 500 watt(e) thermoelectric auxiliary power unit.

SNAP-4 is the program to develop a compact turboelectric generator based on the SNAP-2 hydride fuel technology. The aim is to provide 1,000 to 4,000 kilowatts(e) in an under-water or a remote land location.

The largest space power system presently under development is SNAP-50, with a power rating of up to 1,000 kilowatts(e). This is a long-range program requiring the development of an advanced reactor technology to meet future space requirements.

Reports have also been included on the NAP-100 isotopic generator and the SPUR system although these power generators are not being developed under the SNAP program.

For information on direct energy conversion devices such as are used in many of the SNAP units the Direct Energy Conversion Literature Abstracts series from the Naval Research Laboratory are excellent reference sources. This series is included herein as abstracts 304-307, and the direct energy conversion references included in previous issuances of TID-3561 have been omitted.

References in this search were taken from Nuclear Science Abstracts (NSA), which was searched through April 15, 1964. The references are arranged by issuing organization behind the individual SNAP units. Personal author and report number availability indexes are included.

RADIOISOTOPE UNITS

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SNAP—1

(See also references 140, 141, 207, 211, 285, 319)

Martin-Marietta Corporation, Aerospace Division, Baltimore, Maryland

1 (MND-1086(Del.)) RADIOISOTOPE FUELED AUXILIARY POWER UNIT. Quarterly Progress Report No 1, January 2—April 2, 1957. Calvin C. Silverstein and Robert E. Behmer, comps. (Martin Co., Baltimore). 48p

Progress on an isotope-fueled auxiliary power unit is reported Based on the power requirements of 260 W, it was concluded that Ce^{144} should be used as fuel. Estimates were made of fuel availability and unit cost and weight at power levels of 133, 300, 500, and 1000 W(e). Fuel development, boiler development, system and operational considerations, and the power conservation system are discussed.

2 (MND-1123) RADIOISOTOPE FUELED AUXILIARY POWER UNIT. Quarterly Progress Report No 2, April—July 1957. (Martin Co., Baltimore). Contract AT (30-3)-217. 76p.

Development of a radioisotope heat source for a satellite power plant is summarized Possible operational hazards during the lifetime of the system are discussed. The development of the boiler design, fabrication of cerium compounds, pump assembly, turbine, and mercury heat transfer medium are summarized. The effect of gamma radiation on Kodak Microfile film is studied

3 (MND-2570) SURVEYOR R.T.G. DESIGN STUDY. Preliminary Report. (Martin Co. Nuclear Div., Baltimore). May 12, 1961. 97p.

The design of an isotope fueled thermoelectric generator for the Surveyor Program was evaluated in relation to the over-all spacecraft mission. Generator development, fuel development, and safety are discussed. Contractor requirements are outlined. Generator design features are described including design, performance, materials and weight, sterilization, reliability, and fuel properties. Integration with the spacecraft is also discussed.

4 (MND-P-1175) RADIOISOTOPE FUELED AUXILIARY POWER UNIT. PIED PIPER APU. Quarterly Progress Report No. 3, July 1, 1957—October 1, 1957. (Martin Co., Baltimore). Contract AT(30-3)-217. 51p.

Progress made in the development of SNAP-1 is reported. Drawings of the shielding and remote handling equipment are given. The hazards of this power plant are summarized. The conceptual design of the boiler is revised. The CeO_2 fuel capsules will be mounted in a block of molybdenum by drilling longitudinal holes and inserting. The thermal bond material between the molybdenum block and the mercury bearing coil will be molten lead. Results of studies on fabrication of CeO_2 cermets are given. Equipment for static corrosion testing with mercury and lead is diagramed. Development work on the power conversion system is discussed.

5 MND-P-2128
Martin Co. Nuclear Div., Baltimore.
SNAP I—DYNAMIC MERCURY LOOP TESTS OF SELECTED MATERIALS. [Period covered]: January 1957—June 1959. John McGrew. Mar. 1960. 45p. Contract AT(30-3)-217. OTS.

Six dynamic boiling-mercury loops were tested in connection with the SNAP-I program. The loops were Croloy-5 Si, Croloy-5 Ti, Carpenter 20 Nb, Types 347 and 446 stainless steel and a Type 347 stainless-steel-clad niobium boiler coil inserted into the Type 347 stainless-steel loop. Operation of the Croloy-5 Si loop was discontinued after about 86 hr because the heaters burned out. Extensive general corrosion which penetrated as much as 3.5 mils occurred during this time. The boiler-outlet leg of the Croloy-5 Ti loop ruptured after 166 hr of operation. Again, extensive general corrosion occurred with up to 5 mils penetration. The Carpenter 20 Nb loop was never operated at design conditions. It failed after a short time when arcing from the heater to the coil burned through the tubing. The Type 347 stainless-steel loop failed after 326 hr when the outlet leg of the boiler coil ruptured. Extensive depletion of nickel with penetrations up to 20 mils was found in the condenser. The Type 446 stainless-steel loop did not fail. Its operation was discontinued after 141 hr because of multiple leaks. Numerous transgranular cracks were found in the boiler coil, but the origin of these cracks was problematical. The remainder of this loop was apparently unaffected. The niobium coil ruptured after 50 hr of operation. The failure was probably caused by atmospheric oxygen, which contacted the niobium when the Type 347 stainless-steel cladding failed. Successful operating experiences involving two-phase mercury flow and totalling more than 500 hr were obtained using Type 316 stainless-steel tubing. Operating conditions for the mercury working fluid at the inlet of this tubing were 200 psia and 1100 to 1350°F.

6 (MND-P-2184) PRELIMINARY OPERATIONAL HAZARDS SUMMARY REPORT FOR THE TASK 2 THERMOELECTRIC GENERATOR. George P. Dix, Jr. (Martin Co. Nuclear Div., Baltimore). Dec. 1959. Decl. Oct. 20, 1960. Contract AT(30-3)217. 161p.

The operational hazards associated with the use of an isotope-fueled auxiliary power unit for a satellite mission are described. The effects of missile abort on the generator are discussed. The generator design is described, and the properties of the various fuel forms are investigated. The characteristics of the fuel capsules and the provisions for biological shielding are also described. Integration of the generator into a typical missile system is discussed. Hazards and procedures of transporting and handling the fuel cores from fabrication to launching are considered. Aborted missions are defined, and the forces acting on the generator during abort are described.

7 (MND-P-2291) AERODYNAMIC RE-ENTRY ANALYSIS. TASK 2. THERMOELECTRIC GENERATOR SUMMARY REPORT. Robert Oehrli (Martin Co. Nuclear Div., Baltimore). [1960]. Decl. Apr. 27, 1961. Contract AT(30-1)-217. 41p.

An analytical trajectory and aerothermodynamic analysis of a satellite containing a Task 2 thermoelectric generator was completed. A 300-statute mile circular polar orbit was used for this analysis and the launch was assumed to be from Vandenberg Air Force Base. Results of this study show that upon natural decay from a successful mission, the radio-cerium fuel will burn up in space at high altitude, thus only a very minor amount of radio cerium will be released to the stratosphere. A complete analyses of the fate of the radio-cerium fuel following various aborted launching attempts also was carried out. Charts summarizing the various assumed failures and locations of the fuel following failure are shown. A technical discussion of the methods used in performing the analysis is included in the report.

8 (MND-P-2309) SNAP I MERCURY BOILER DEVELOPMENT, JANUARY 1957 TO JUNE 1959. John Jicha and James J. Keenan (Martin Co. Nuclear Div., Baltimore). June 1960. 102p. Contract AT(30-3)-217.

The mercury-boiler development program was undertaken to develop a system that would utilize the heat of radioisotope decay to boil and superheat mercury vapor for use with a small turbine-generator package. Through the use of a Rankine cycle, the mercury vapor can be provided continuously to power a turbine-driven alternator and produce electricity for extended periods of time. This mercury boiler and the related power-conversion system was planned for a satellite that would orbit the earth. This system design and development program was designated as SNAP-I Development of the mercury boiler is described and a chronological description of the various mercury-boiler concepts is presented. The applicable results of an extensive literature survey of mercury are included. The mercury-boiler experimental-test-program description provides complete coverage of each experimental boiler and its relation to the system design of that period A summary of all mercury boilers and their final disposition is also given.

9 (MND-P-2335) INTERIM REPORT ON SAFETY PROCEDURES FOR THE TASK 2 THERMOELECTRIC GENERATOR. L. T. Klein (Martin Co. Nuclear Div., Baltimore). Mar. 15, 1960. 62p. Contract AT(30-2)-217. OTS.

Operational hazards associated with the use of a radioisotope-fueled auxiliary power unit for a satellite mission are evaluated. The entire fabrication-to-flight and/or retrieval and disposal sequence is examined and safe handling procedures suggested. The design and operation of the Task 2 thermoelectric generator is discussed.

10 (MND-P-2342) 100-WATT CURIUM-242 FUELED THERMOELECTRIC GENERATOR—CONCEPTUAL DESIGN. SNAP Subtask 5.7 Final Report. J. B. Weddell and Justin Bloom (Martin Co. Nuclear Div., Baltimore). May 1960. 66p. Contract AT(30-3)-217.

A thermoelectric generator which produces 100 watts of electrical power continuously over a six-month operational life in a space environment was designed. It employs the heat produced by the decay of Cm^{242} as the source of power. Uniform output over the operational life of the generator is accomplished by means of a thermally actuated shutter which maintains the hot junction temperature of the thermoelectric converter at a constant figure by varying the amount of surplus heat which is radiated directly to space from the heat source. The isotopic heat source is designed to safely contain the Cm^{242} under conditions of launch pad abort and rocket failure, but to burn up upon re-entry to the earth's atmosphere from orbital velocity.

11 MND-P-2349
Martin Co. Nuclear Div., Baltimore.
SNAP-1A FUEL CORE MATERIALS DEVELOPMENT SUMMARY. [Period covered]: July 1959 through June 1960. 87p. Contract AT(30-3)-217. OTS.

Several materials were evaluated for use as the fuel container material for the SNAP 125-w thermoelectric generator. The materials were subjected to air oxidation, mercury and sea water corrosion, liquid O_2 resistance, and fuel compatibility tests. Of the materials tested, Inconel X and Allegheny Ludlum S-816 exhibited the better qualities. For fuel materials, CeO_2, Ce_2O_3, CeF_3, and mixtures of these materials were evaluated relative to fabrication, burnup and high-temperature properties. The fuel material selected consists of $Ce^{144}O_2$ (+10% by weight of SiC) or $Ce^{144}F_3$. At a heating rate of 180 Btu/ft^2-sec, a 1-in.-diam pellet of CeO_2 + 10% SiC would burn up in 30 sec; a similar pellet of CeF_3 would burn up in 65 sec. Plasma flame tests showed that the fuel container materials considered (Inconel X, Allegheny Ludlum S-816, and Type 316 stainless steel) would melt and ablate during re-entry from orbit. At a heating rate of 100 Btu/ft^2-sec, material recession rates were determined to be 2, 2.5, and 5.5 mils/sec for Inconel-X, Allegheny Ludlum S-816, and Type 316 stainless steel, respectively.

12 (MND-P-2350) SNAP I RADIOISOTOPE-FUELED TURBOELECTRIC POWER CONVERSION SYSTEM SUMMARY, JANUARY 1957 TO JUNE 1959. Paul J. Dick (Martin Co. Nuclear Div., Baltimore). June 1960. Contract AT(30-3)-217. 60p.

The SNAP I development program was initiated to develop a 500-watt turboelectric power conversion system for space applications. Superheated mercury vapor was used as the heat conversion working fluid. The conversion system was to obtain thermal energy from the decay of a radioisotope fuel such as Ce^{144}. Each of the major components and systems is summarized with respect to initial design objectives, development progress to the point of program termination, results obtained from tests and, where indicated, future growth potential. Reference is made to 10 other reports which describe, in detail, the major components of this power generating system. Also included is a bibliography of documented reports that are related to the power conversion system design criteria or system integration into a flight vehicle.

13 (MND-P-2352) FINAL SAFETY ANALYSIS REPORT—SNAP 1A RADIOISOTOPE FUELED THERMOELECTRIC GENERATOR. George P Dix Martin Co. Nuclear Div., Baltimore. June 30, 1960. 200p. Contract AT(30-3)-217 OTS.

The safety aspects involved in utilizing the Task 2 radioisotope-powered thermoelectric generator in a terrestrial satellite are described It is based upon a generalized satellite mission having a 600-day orbital lifetime A description of the basic design of the generator is presented in order to establish the analytical model. This includes the generator design, radiocerium fuel properties, and the fuel core. The transport of the generator to the launch site is examined, including the shipping cask, shipping procedures, and shipping hazards A description of ground handling and vehicle integration is presented including preparation for fuel transfer, transfer, mating of generators to final stage, mating final stage to booster, and auxiliary support equipment. The flight vehicle is presented to complete the analytical model. Contained in this chapter are descriptions of the booster-sustainer, final stage, propellants, and built-in safety systems The typical missile range is examined with respect to the launch complex and range safety characteristics. The shielding of the fuel is discussed and includes both dose rates and shield thicknesses required. The bare core, shielded generator, fuel transfer operation, and dose rates for accidental conditions are treated The mechanism of re-entry from the successful mission is covered Radiocerium inventories with respect to time and the chronology of re-entry are specifically treated. The multiplicity of conditions for aborted missions is set forth The definition of aborted missions is treated first in order to present the initial conditions Following this, a definition of the forces imposed upon the generator is presented The fate of the radiocerium fuel following both successful and aborted missions is presented. A large number of initial vehicle failure cases is narrowed down into categories of consequences Since stratospheric injection of fuel results in cases where the fuel is not contained after re-entry, an extensive discussion of the fall-out mechanism is presented

14 (MND-P-3001) RADIOISOTOPE FUELED AUXILIARY POWER UNIT. Quarterly Progress Report No. 4, October 1957–January 1958. (Martin Co., Baltimore). Contract AT(30-3)-217. 73p.

Work was directed toward building a suitable mercury heat transfer loop that can be operated with a full-size boiler mockup under environmental conditions of both launch and outer space. A new half-power boiler mockup was designed to replace the full-size boiler in the heat transfer test loop. Fuel assembly studies were made on the stabilization of CeO_2 and the oxidation of molybdenum. Corrosion test results on stainless steels, chromium steels, and nickel alloys in contrast with liquid lead, mercury vapor, and liquid mercury are presented. The test rig checkouts were essentially completed and testing was initiated in every area of the power conversion system program. All component groups were directed toward obtaining experimental verification of the individual component designs established for the turbine-alternator dynamometer.

15 (MND-P-3002) RADIOISOTOPE FUELED AUXILIARY POWER UNIT. Quarterly Progress Report No. 5, January–April 1958. (Martin Co., Baltimore). Contract AT(30-3)-217. 60p.

Progress made in the development of the radioisotope-fueled thermoelectric generator (SNAP-1) is reported. Shipping procedures and the boiler loading and installation philosophy were determined. The core integrity test program was defined in further detail to include tests to evaluate launch abort damage and simulate re-entry heating conditions. A shielding analysis, to facilitate design of the boiler insulation and biological shield, was completed. Assembly of the mockup boiler heat transfer loop was completed and initial testing started Engineering drawings for the new half-power boiler were completed and fabrication initiated. Development testing continued on CeO_2 pellets to improve stability and corrosion resistance. A corrosion program to determine the effect of biological shield mercury on surface emissivities of insulating metal was initiated. Development of the power conversion system components (turbine, pump, controls, alternator, and bearings) was continued.

16 (MND-P-3003) RADIOISOTOPE FUELED AUXILIARY POWER UNIT. Quarterly Progress Report No. 6, April 1958–July 1958. (Martin Co., Baltimore). Contract AT(30-3)-217. 125p.

A modular concept has evolved which permits testing of SNAP-1 as an attachable unit. Integrity testing of fuel elements in simulated pad aborts is reported. The adequacy of a full-scale boiler mockup in vaporizing mercury at the design point was tested; a new boiler coil designed to prevent slugging was tested. The sintering properties of CeO_2 were further investigated. Dynamic mercury corrosion testing of Croloy 5 Si and Croloy 5 Ti is reported. Static lead tests of CeO_2 pellets, brazed joints, and flame sprayed coatings continued Testing of the power conversion system turbine, centrifugal pumps, controls, radial gap alternator, bearings, and steels is described. Design of a facility for testing the APU module is under way. A conceptual design of SNAP-3 was delineated

17 (MND-P-3004) RADIOISOTOPE FUELED AUXILIARY POWER UNIT. Quarterly Progress Report No. 7, July–September 1958 (Martin Co., Baltimore). Contract AT(30-3)-217. 116p.

Progress made in the development of SNAP-1 and -3 is reported. SNAP-1 development reported includes: boiler development, fuel development, properties of cerium dioxide, materials corrosion, power conversion system development, shielding analysis, hazards evaluation, and ground test development SNAP-3 development includes: power conversion analysis, thermoelectric generator development, and fuel element development. Information is given on the handling and transportation equipment for SNAP-1.

18 (MND-P-3008) RADIOISOTOPE FUELED AUXILIARY POWER UNIT. Quarterly Progress Report No 11, July–September 1959. (Martin Co Nuclear Div., Baltimore). Contract AT(30-3)-217. 144p.

Progress made in the development of the radioisotope-fueled thermoelectric generators (SNAP-IA, SNAP-IIIA, -B, -C, and -D, and SNAP-VII) is reported SNAP-IA development is reported in relation to the overall system, structure and containment, heat element development and testing, environmental and qualification testing, ground handling and transportation, conversion system, and operational hazards. SNAP-III-A, -B, -C, and -D development of the thermoelectric generator is concerned mostly with molybdenum fuel capsule development, vehicle integration, fuel element design and testing, generator design and testing, and hazards testing. SNAP-VII development is concerned with generator design, fuel development, program management and integration, and hazards analysis

19 (MND-P-3009) RADIOISOTOPE FUELED AUXILIARY POWER UNIT TASK 2 Quarterly Progress Report No 12, September–December 1959 (Martin Co Nuclear Div , Baltimore). Contract AT(30-3)-217 115p

Progress made in the development of the radioisotope-fueled thermoelectric generator (SNAP-IA) is reported Information is given on system design, material analysis, hazards analysis, fabrication techniques, and system and components testing Special emphasis is given to the cerium fuel development program

20 MND-P-3011
Martin Co. Nuclear Div., Baltimore.
SNAP PROGRAMS Quarterly Progress Report No 3 [for] April 1 through June 30, 1960. 162p. Contract AT(30-3)-217. OTS.

Design studies were made for the cooling, shielding, and electrical-control support systems required for the testing of the isotope-fueled 125-w generator in a hot-cell facility A ceric oxide fuel containing 10 wt. % SiC exhibited suitable burn-up characteristics in simulated postorbital re-entry heating conditions. Inconel X was selected as the fuel-containment material. Negative pitch angle injections were evaluated for the injection-stage flight vehicle. The second electrically heated 125-w generator was assembled and prepared for checkout A successful reproducible process for bonding the p element was developed in which GeTe was furnace melted into an iron shoe and a spring-loaded element was bonded to the shoe in an induction furnace. The p element contact resistance was 0.1 milliohm. The maximum output on the first generator was measured as 78.2 w. Measurements were stopped when power output deteriorated to 28.8 w. An inspection showed that oxidation due to insufficient reducing atmosphere at the hot junction contacts was the cause. Parametric thermoelectric generator performance tests were conducted in which the internal gas pressure was varied from 0 to 1.5 atm and the external pressure was either 1 atm. or a vacuum. The fabrication, operation, and performance of cesium diodes were studied. The effect of a molybdenum powder film on heat transfer when placed in a molybdenum–tungsten interface was determined. In development studies on a low-power thermionic generator, cathode and sapphire-support creep tests were conducted up to 500°C, at which temperature no creep was observed. The design of Generator 2A was completed. A heater was developed for the generators which is capable of simulating the power density of a Cm^{242} heat source. A titanium alloy, A-70, was found which possessed satisfactory properties for use as a lead-through at 1050°C. A method of electrically insulating the two stages of a generator was developed. Tests were performed which showed that no interaction takes place between Ce_2O_3 and molybdenum in an oxygen atmosphere at 1600°F. Methods for removing aluminum from a curium capsule by volatilizing in either bromine or chlorine gas were investigated. An analysis to determine the helium pressure build-up in aluminum-americium capsules was conducted Dose rates were determined for americium slugs before irradiation at distances from the slug surface up to 1 m. An evaluation of the effectiveness of the curium shipping cask was made. The power release by decay products of Pu^{236} and U^{232} was determined. Equations are presented concerning the reaction kinetics involved in the neutron irradiation of Am^{241} with the subsequent production of Cm^{242}. (For preceding period see MND-P-3010.)

21 (MND-P-3012-I) SNAP PROGRAMS Quarterly Progress Report No 4 for July 1 through September 30, 1960 Tasks 2 and 3 P J Dick, comp and ed (Martin Co Nuclear Div , Baltimore) 53p Contract AT(30-3)-217 OTS

SNAP-1A All ground handling equipment required to accomplish hot-cell welding of the fuel core closure seals, fuel core transportation, generator fuel core loading, and isotope generator handling was completed in manufacturing Functional tests of this equipment to determine its conformance to prescribed ground handling procedures were initiated Final assembly of the G-2 generator was completed and performance tests with an electrically heated source block were made The generator was removed from the test chamber in preparation for vibration tests Two Inconel X source containers for Ce^{144} fuel loading were machined and assembled In addition, three practice cores for remote welding test purposes were fabricated Dissimilar metal seals of stainless steel and aluminum for use at six closure areas between the G-3 generator inner and outer skins were completed A pressure-tight seal was obtained at the stainless-steel-to-aluminum interface by ultrasonic welding Evaluation and testing of high-temperature resistance electrical insulation coatings were accomplished for possible application to the G-3 generator stainless-steel hot skin A Bureau of Standards A-418 ceramic film formulation showed good adherence at elevated temperature and satisfactory electrical resistance at room temperature SNAP-III SNAP III generator, 3M-1G-10, has completed 250 days of continuous life test operation It has been operating since January 26, 1960 Power output was 1 96 watts (e) at the end of this reporting period compared with 2 25 watts at the beginning of this quarter and 3 45 watts at the start of life tests. Preparations were made to fuel SNAP III generator 1-G-5 with 2000 curies of Po^{210} (For preceding period see MND-P-3011)

22 (MND-P-3013-I) SNAP RADIOISOTOPE SPACE PROGRAMS, TASK 2, 3 AND 7, QUARTERLY PROGRESS REPORT NO. 5, OCTOBER 1 THROUGH DECEMBER 31, 1960. (Martin Co. Nuclear Div., Baltimore). Contract AT(30-3)-217. 46p.

Functional testing was completed on the ground handling equipment for transporting the Ce^{144} heat source container and loading the SNAP 1A generator. Mercury shield fill and drain tests for the generator system and the collar shield were conducted. Heat-transfer tests of the isotope heat source shipping cask were conducted. Simulated rocket-launch environmental tests of vibration, acceleration, and shock were completed on the G-2 generator. Analysis of the environmental test data was initiated. Final design studies for the G-3 generator were completed, and a thermoelectric module concept was selected for use in the isotope-fueled generator. Development tests of thermoelectric modules in a module tester were initiated Voltage breakdown tests were conducted on a porcelain enamel spray coat. The material was evaluated for application to the G-3 generator inner skin as a possible second discrete barrier against hot junction electrical shorts. SNAP 3 generator 3M-1G10 completed 322 days of life test operation, and the power input was terminated after the generator was operated under a full range of external loads to obtain performance characteristics. Electrical power output after 322 days at steady-state heat source and external load conditions was 1.92 watts, for an over-all efficiency of 2.9%. Tear-down inspection of the generator confirmed previous indications of increased internal electrical resistance and thermal conductivity, which account for the gradual reduction in generator performance from the start-of-life electrical output of 3.45 watts and 5.2% over-all efficiency. The SNAP 3 3M-1G5 generator was successfully fueled with Po^{210}. Maximum electrical power output was 4 watts at an over-all efficiency of 5.2%. Radiological safety studies for space power were initiated. (For preceding period see MND-P-3012-I.)

TAPCO. Division of Thompson Ramo Woolridge Incorporated, Cleveland, Ohio

23 (NAA-SR-6308) SNAP II POWER CONVERSION SYSTEM TOPICAL REPORT NO. 16, 2500-HOUR ENDURANCE TEST OF MERCURY RANKINE CYCLE POWER SYSTEM. Paul E. Grevstad (Tapco. Div. of Thompson Ramo Wooldridge Inc., Cleveland) Jan. 1961. For Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif. Contract [AT-11-1-GEN-8], Subcontract N 843 FS-101221. 64p.

SNAP 1 is the designation for the 0.5-kw nuclear auxiliary power supply intended for application in a satellite. SNAP 1 was designed to convert thermal energy from the decay of a radioisotope into electrical energy using a Rankine engine with mercury as the working fluid. A successful 2500-hour endurance test is described of a complete developmental version of the SNAP 1 power conversion system utilizing a prototype turbomachinery package, an electrically heated boiler, and an air-cooled condenser. Indications from the data obtained during the test and from inspection of the system following the test were that many more hours of satisfactory operation could have been obtained on all major system components except the rotating unit pump. The mercury-lubricated bearings, the turbine, and the alternator, all demonstrated excellent endurance capability. Based on previous component tests, it is concluded that the pump performance deterioration was caused by air entrainment in the liquid Hg.

Thompson-Ramo Wooldridge, Inc., New Devices Laboratory, Cleveland, Ohio

24 MND-P-2375
Thompson Ramo Wooldridge Inc. New Devices Labs., Cleveland.
SNAP I POWER CONVERSION SYSTEM DEVELOPMENT. Period covered: February 1, 1957 to June 30, 1959. R. C. Biering, D. D. Carrell, P. E. Grevstad, N. P. Otto, J. W. Picking, G. M. Thur, and R. F. Wulf. June 20, 1960. 68p. For Martin Co. Contract AT(30-3)-217. (ER-4050). OTS.

Development of the SNAP I power conversion system is described. The system is designed to convert the thermal energy produced by the decay of radioisotopes into 500 watts of electrical energy by means of a mercury Rankine cycle. A list of specific accomplishments of the program is included.

25 MND-P-2376
Thompson Ramo Wooldridge Inc. New Devices Labs., Cleveland.
SNAP I POWER CONVERSION SYSTEM TURBINE DEVELOPMENT. Period covered: February 1, 1957 to June 30, 1959. D. C. Reemsnyder and E. M. Szanca. June 20, 1960. 54p. For Martin Co. Contract AT(30-3)-217. (ER-4051). OTS.

Turbine development for the SNAP I power conversion system is described. A three-stage axial flow turbine with the first two impulse stages partial admission and the last stage full admission with a slight amount of reaction was selected. Other design and performance data are included.

26 MND-P-2377
Thompson Ramo Wooldridge Inc. New Devices Labs., Cleveland.
SNAP I POWER CONVERSION SYSTEM ALTERNATOR DEVELOPMENT. Period covered: February 1, 1957 to June 30, 1959. H. J. Morgan June 20, 1960. 43p. For Martin Co. Contract AT(30-3)-217. (ER-4052). OTS.

Alternator development for the SNAP I power conversion system is described. A radial air-gap permanent-magnet 6-pole single-phase 2000-cps alternator, rated at 530 watts, 0.8 power factor, and 115 volts was selected. Discussion of requirements and specifications, design and performance, test facilities, and conclusions are included.

27 MND-P-2378
Thompson Ramo Wooldridge Inc. New Devices Labs., Cleveland.
SNAP I POWER CONVERSION SYSTEM PUMP DEVELOPMENT. Period covered February 1, 1957 to June 30, 1959 E. S. Kovalcik and D. C. Reemsnyder. June 20, 1960. 59p. For Martin Co. Contract AT(30-3)-217. (ER-4053). OTS.

Pump development for the SNAP I power conversion system is described. A four-vaned impeller pump supplemented by a jet boost stage was selected for development to meet the final design requirements. Information on other designs, pump test facilities, and conclusions are included.

28 MND-P-2379
Thompson Ramo Wooldridge Inc. New Devices Labs., Cleveland.
SNAP I POWER CONVERSION SYSTEM BEARINGS DEVELOPMENT. Period covered: February 1, 1957 to June 30, 1959. R. Meredith, G. Y. Ono, and D. C. Reemsnyder. June 20, 1960. 68p. For Martin Co. Contract AT(30-3)-217. (ER-4054). OTS.

Development of bearings for use in the SNAP I power conversion system is described. Liquid mercury, lubricated hydrosphere bearings were selected. Design and performance data are given along with conclusions.

29 MND-P-2380
Thompson Ramo Wooldridge Inc. New Devices Labs., Cleveland.
SNAP I POWER CONVERSION SYSTEM CONTROL DEVELOPMENT. Period covered: February 1, 1957 to June 30, 1959. W. E. Dauterman, M. W Mueller, and E. J. Viton. June 20, 1960. 50p. For Martin Co. Contract AT(30-3)-217. (ER-4055) OTS.

Development of the control elements for the SNAP I power conversion system is described. A description of test and prototype hardware and performance data are included The control package in its final design is a combination of regulator and speed-sensitive feedback which provides satisfactory steady-state operation and serves as a mechanism correction for system disturbances.

30 MND-P-2381
Thompson Ramo Wooldridge Inc. New Devices Labs., Cleveland.
SNAP I POWER CONVERSION SYSTEM CONDENSER-RADIATOR DEVELOPMENT. Period covered: February 1,

1957 to April 15, 1959. R. J. Kiraly and D. C. Reemsnyder. June 20, 1960. 47p. For Martin Co. Contract AT(30-3)-217. (ER-4056). OTS.

Development of the condenser-radiator for use in the SNAP I power conversion system is described. Although no prototype hardware was designed or tested in the program, the concept of rejecting waste by radiation in a gravitationless environment was proved feasible.

31 MND-P-2382

Thompson Ramo Wooldridge Inc. New Devices Labs., Cleveland.

SNAP I POWER CONVERSION SYSTEM MATERIALS DEVELOPMENT. Period covered: February 1, 1957 to June 30, 1959. V. F. Hambor and J. J. Owens. June 20, 1960. 38p. For Martin Co. Contract AT(30-3)-217. (ER-4057). OTS.

Investigations of materials for use in connection with the SNAP I mercury Rankine cycle power conversion system are discussed. Test programs are outlined and results are tabulated for each candidate material. Several nonmetallic materials and processing procedures were developed which enabled uncooled high-performance electric machinery to operate at 550°F in mercury vapor.

SNAP—3

(See also references 16, 17, 18, 20, 21, 22, 207, 211, 285, 294, 319)

Lockheed Aircraft Corporation, Sunnyvale, California

32
OPTIMIZED SNAP III POWER GENERATOR DESIGN FOR SPACECRAFT H. H. Greenfield (Lockheed Aircraft Corp Sunnyvale, Calif.) Paper No 1278-60. Presented at the ARS Space Power Systems Conference, Santa Monica, California, September 27-30, 1960. New York, American Rocket Society, 1960. 35p.

Design performance studies on the original SNAP III type of thermoelectric generator were made to optimize its use as a power system for special spacecraft missions. From laboratory and analytical studies on the generator's performance and thermal energy rejection characteristics in a space environment, it was determined that the initial available electrical power can be increased by as much as a factor of four. The electrical power is increased by increasing the thermal input of the generator at the expense of conversion efficiency. The modification to the SNAP generator consists of increasing the diameter of the thermoelectric elements and decreasing their length as well as modifying the fuel container and hot shoes to physically accommodate the thermoelectric element. However, the over-all physical characteristics of the SNAP III generator—dimensions, number and type of thermoelectric elements, method of hot and cold junction contacting, hot and cold temperature limits, radial arrangement, number of thermoelectric element rows, and thermal insulation—remain unchanged in the modified design.

Martin-Marietta Corporation, Aerospace Division, Baltimore, Maryland

33 (MND-P-2047) HAZARDS SUMMARY REPORT FOR A THREE WATT POLONIUM-210 FUELED THERMOELECTRIC GENERATOR (Martin Co Nuclear Div, Baltimore) June 1959 Decl Sept 19, 1960 36p

A hazards survey was made of the Auxiliary Power Unit (APU) for space vehicle applications The APU utilizes the decay process from 1570c of Po^{210} to generate thermal energy The design is described and diagrams are given The factors involved in the integration of the thermoelectric generator into the Discoverer or Sentry vehicles are discussed The physical chemical, nuclear, and radiobiological properties of Po^{210} are given The shielding requirements for the APU are outlined The principal environmental hazard is that imposed by the toxicity of the radionuclide fuel when released to the biosphere Hazards design criteria were determined by extreme conditions including handling accidents missile vehicle failures, and re-entry through the atmosphere and subsequent earth impact

34 MND-P-2101
Martin Co. Nuclear Div., Baltimore
SNAP-III—THERMOELECTRIC GENERATOR ENVIRONMENTAL TEST. Louis W. Gross. Aug. 1959. 68p $10.80(ph), $3.90(mf) OTS.

The effects of simulated space vehicle vibration, acceleration, and shock on the operation and efficiency of a SNAP-III thermoelectric generator are described. The test specifications were developed by Jet Propulsion Laboratories for the third stage and payload of the Vega Vehicle.

35 (MND-P-2101-II) SNAP III—THERMOELECTRIC GENERATOR ENVIRONMENTAL TEST VOLUME II Louis W Gross (Martin Co Nuclear Div Baltimore) Oct 1959 Decl Sept 21 1960 50p

The thermoelectric generator operated for about 250 hr during the entire test program The efficiency varied ~5% of the total performance during the vibration cycle, and remained relatively stable during the acceleration and shock tests Recovery was complete in all cases Oscillatory d-c superimposed on the d-c output of the generator was observed during the shock and vibration tests and disappeared when the environmental forces were discontinued The maximum d-c ripple was 7 4 millivolts rms in the y-Plane during the shock and vibration cycles It was concluded that SNAP III thermoelectric generator No 1G5 is reliable in environments simulating the WS-117 L Vehicle

36 MND-P-2101-III
Martin Co Nuclear Div, Baltimore
SNAP-III—THERMOELECTRIC GENERATOR ENVIRONMENTAL TEST VOLUME III Louis W Gross and Eugene J Schramm Jan 1960 73p Contract AT(30-3)-217 OTS

The results of tests on four thermoelectric generators (two each of two different configurations) of the Snap III type to both the J P L and the L M S D specifications for shock, vibration, and acceleration test are reported The simulated levels were based on the anticipated environments of the Vega (J P L) and WS117L (L M S D) systems All four generators exhibited the same characteristic behavior pattern throughout the vibration portion of the test program, showing a d-c ripple in the generator output only in the Y plane. This behavior of the generator is attributed to the oscillatory change in internal resistance resulting from vibratory elastic deformation of the thermoelectric elements. This produces a transient in the electrical output with a resultant reduction in generator efficiency. The maximum reduction in efficiency was noted in the 700 cps region. A resonance on the generator shell at 1845 cps was noted, but generator electrical output and efficiency were not affected. Upon discontinuance of the induced vibration, the generators returned to normal operating conditions. While undergoing shock test, a d-c transient was noted at the time of impact, resulting in a slight decrease in efficiency. The generators immediately returned to their normal operating efficiency. In the acceleration portion of the test no d-c transient was evident in any of the three planes, therefore the generator efficiency remained constant. Steady state conditions were re-established at the start of each new test phase (i.e., changing planes of excitation, changing from shock to vibration, etc.). Thus, any variation from pretest efficiency was attributed to the external load resistance becoming unmatched due to the change in internal resistance. The important result is that complete generator recovery was consistent in all cases and normal operation continued. The generator, shell, internal structure and pressure, and the hot and cold junction temperature were not affected during the test. As a result of this test program, it was concluded that the Snap III thermoelectric generator will operate reliably in the environments associated with the Vega and WS117L vehicles.

37 MND-P-2355
Martin Co. Nuclear Div., Baltimore.
ADVANCED THERMOELECTRIC POWER SYSTEM. Final Report. Robert J. Harvey. 1960. 20p. Contract AT(30-3)-217. OTS.

Development of a radioisotope-fueled thermoelectric power-conversion system for the SNAP program is discussed. The generator operates at somewhat less than 1% over-all efficiency, has a power output of approximately 1.45 watts, and has a specific power of 0.142 watts per pound. The power-flattening device did not perform as expected. A second generator is also described which produces a maximum power of 1.6 watts, has a maximum efficiency of 1.20%, and has a specific power of 0.32 watts per pound (exclusive of the weight of the heat source).

38 MND-P-2363
Martin Co. Nuclear Div., Baltimore.
PRELIMINARY SAFETY ANALYSIS LOW POWER CERIUM-144 GENERATOR. June 1960. 33p. Contract AT(30-3)-217. OTS.

A safety analysis of small Ce^{144} fueled thermoelectric generators for use in terrestrial satellite systems is given. The Ce^{144} fuel is enclosed in a capsule of Haynes-25, which is to be maintained at 580°C during operation. Lead telluride thermoelectric elements surround the capsule and are contained in an outer stainless steel shell. In one configuration a second shell filled with Hg is used for biological shielding. The biological shield reduces the direct radiation dose from decay gammas and bremsstrahlung to 90 mr/hr at 3 ft. The integrity of the fuel capsule under the spectrum of launch failure forces is considered. These forces include internal pressure, external forces from shock overpressures and impact, corrosion, and propellant fires. Following successful missions, the fuel is to be released in the stratosphere at a time when the source strength is about 4000 c. Resultant ground concentrations would be 2×10^{-9}c/sq mile and 0.053 mc/sq km for temperate zone and prompt stratospheric releases, respectively.

39 (MND-P-2369) CONCEPTUAL DESIGN OF A SNAP III TYPE GENERATOR FUELED WITH CERIUM-144. Robert J. Wilson (Martin Co. Nuclear Div., Baltimore). June 1960. 48p. Contract AT(30-3)-217.

A design concept is presented for an electrical system using two SNAP III type generators fueled with cerium. In the modified SNAP III generator, a capsule of Haynes 25 contains 9725 curies of cerium oxide pellets, which will provide 67 thermal watts at time of launch Sufficient void volume and capsule strength ensure containment of the oxygen evolved through isotope decay during the operational life of the generator. Thermal converter configuration in the conceptual generator is identical to that of the SNAP III except that the shell is stainless steel. Two methods of biological shielding are considered. The first uses mercury contained in a sphere surrounding the generator. In the second concept, a lead cask shields the unit until its installation in the launch vehicle A remote installation procedure and an equipment arrangement are proposed. Generator output predictions were based on actual test data. The output of a single unit would be 3.8 watts at launch, decreasing to 1.9 watts in the course of a 6-month mission. A ground-handling procedure and conceptual designs of the equipment are included.

40 MND-P-2398
Martin Co. Nuclear Div , Baltimore
SNAP III FINAL PERFORMANCE TEST SUMMARY
James D. Long Aug. 1960. 57p. Contract AT(30-3)-217 OTS.

SNAP III, a 3- to 5-watt electrical generator, was designed as a proof-of-principle device in the development of radioisotope-powered thermoelectric power-conversion systems A program involving five development areas was employed in achieving this aim. These areas were (1) generator development, fuel encapsulation, and handling techniques, (2) system safety studies, (3) system dynamic tests, (4) system parametric performance tests, and (5) system life tests Particular attention was given to fuel encapsulation and handling techniques, system safety studies, system parametric performance tests, and system life tests

41 (MND-P-2398(Add.1)) Snap III. FINAL PERFORMANCE TEST SUMMARY. (Martin Co Nuclear Div., Baltimore). Mar. 1961. Contract AT(30-3)-217. 13p.

This report includes data obtained during the final six months of a life test program on the SNAP 3, 3M-1G10 generator and supplements information previously discussed in Section E of the Final Performance Test Summary. The life test was initiated on January 26, 1960, and 322 days of continuous operation at steady-state power input conditions were completed on December 13, 1960. The thermal power input to the generator was terminated on December 19, 1960, after the generator had been operated under a full range of external loads for determining post-life-test performance characteristics. The electrical power output after 322 days at steady-state heat source conditions and external load conditions was 1.92 watts, corresponding to an over-all efficiency of 2.9%. Teardown inspection of the generator confirmed previous indications of increased internal electrical resistance and increased thermal conductivity These conditions resulted from lead telluride sublimation at thermoelectric hot junction temperatures of 950 to 1000°F and occurred primarily during the first 60 days of operation, when 54% of the total performance reduction took place These observations account for the gradual reduction in generator performance from its start-of-life electrical output of 3 45 watts and over-all efficiency of 5 2%

42 MND-P-2513
Martin Co. Nuclear Div., Baltimore.
SNAP-III—THERMOELECTRIC GENERATOR RADIOLOGICAL SAFETY ANALYSIS. George P. Dix, Thaddeus J. Dobry, Jr., and Paul Guinn. Feb. 1959. 27p. $4.80(ph), $2.70(mf) OTS.

A radiological safety analysis is presented for the SNAP-III thermoelectric generator. Since the fuel of the device is polonium-210, a toxic radioisotope, certain safety measures have been designed into the device and its shipping container to prevent a release of the contaminant into any environment during normal operation or a catastrophic accident. Once containment is assured, the direct radiation problem is considered. It has been shown that the direct radiation from the thermal source is kept within tolerance limits by surrounding materials and spatial and temporal factors. It must be emphasized that this device should not be deliberately abused or mishandled since this would serve to increase the probability of accident. The device has been evaluated with respect to internal forces such as heat and helium pressure and external forces such as impact and chemical attack. The mechanical, thermal and chemical integrity of the thermoelectric generator is shown to be quite reliable. The basic physical, chemical, thermal, atomic and nuclear characteristics of polonium-210 have been presented. Potential internal and external radiation hazards have been set forth.

43 MND-P-2514
Martin Co. Nuclear Div., Baltimore
SNAP-III—THERMOELECTRIC GENERATOR SAFE HANDLING PROCEDURES. Thaddeus J. Dobry, Jr. and Paul Guinn. Apr. 1959. 18p. $3.30(ph), $2.40 (mf) OTS.

A method for the safe handling of the SNAP-III thermoelectric generators is presented. It provides information regarding shipping regulations, general handling instructions for packing, unpacking, and demonstrating the device, and procedures to follow in an event of an accident. Possible hazards involved in handling the device, and the probability of any of these hazardous incidents occurring while it is being demonstrated, are summarized. Containment of the radioisotope fuel used in the SNAP-III device was assured under rigorous conditions, including short time external thermal temperature excursions to 1600°C, when in the shipping container. The probability of the device encountering such temperatures are remote.

44 (MND-P-3009-1) SNAP PROGRAMS Quarterly Progress Report No. 1 [for] October 22—December 31, 1959 (Martin Co Nuclear Div., Baltimore) Nov 1960 Contract AT(30-3)-217 287p

An analysis was made of the SNAP III generator to determine the cause of failure, and the test specifications were revised in line with the findings During calibration and demonstration runs with the SNAP III-A generator, a leak developed in the valving mechanism of the variable heat-dump system An examination disclosed that the valve was not satisfactory, so the generator was returned to the manufacturer for repair A description is given of the generator, along with a performance evaluation program A discussion is given of the work performed in advancing the technology of thermionic converters, specifically to increase efficiency by developing better emitter and collector materials and by reducing heat losses Investigations were made in the areas of cesium diodes, effects of cesium on materials, electrical heaters, diffusion of gases through metals, and work function tests Work done on the development of low-power thermionic generators included prototype development, heat-transfer studies and tests, vacuum tests in prototype shells, cathode and sapphire creep tests, a parametric study, the development of molybdenum fuel capsules, heliarc welding of molybdenum fuel capsules, hazards studies on Ce^{144} thermionic units, fabrication of a containment cask for Ce^{144} units, and fueling molybdenum capsules with Ce^{144} pellets Investigations were made of the operational capabilities of SNAP-III type generators through tests simulating the anticipated environments to obtain information for conceptual designs to produce 2 to 5 watts of electrical power Accomplishments in the development of a 1-watt nuclear power supply include the establishment of the over-all generator configuration, the sizing and arrangement of the Pu^{238} fuel, the analysis for helium pressure build-up within the fuel capsule, the selection and sizing of thermoelectric elements, a radiator design, the insulation arrangement, and the thermal analysis of the configuration Work performed on the conceptual design of a 100-watt thermoelectric generator was devoted to heat-transfer analysis, isotope requirements, basic configuration design studies, selection and optimization of thermoelectric generator parameters, radiation shield design, evaluation of fuel containment problems under conditions of helium evolution, and the measurement of thermoelectric materials data Analyses of heat-transfer and radiation shielding and studies of generator and component designs resulted in an optimum configuration for a 13-watt generator of the radiative-cylindrical type The weight of the generator, exclusive of voltage regulation equipment, is ~8 6 lb; the over-all efficiency is 6 2% Fuel-technology development studies were directed toward a parametric study of radioisotopes suitable for isotopic power, the feasibility of processing the selected isotopes, and the selection of purification procedures

45 (MND-P-3010) SNAP PROGRAMS, TASKS 2, 3, 5 AND 6; QUARTERLY PROGRESS REPORT No. 2, JANUARY TO MARCH 31, 1960. (Martin Co. Nuclear Div., Baltimore). Dec. 1960. 331p.

System Design. A chem-milled outer skin, an improved thermoelectric element adjustment and access plug, a flexible stainless steel-aluminum joint welded via ultrasonic techniques, a flexible hot shoe assembly, and thermal hydraulic heat dump system were incorporated into the design of the environmental and ground test generators. Materials Analysis. Burnup studies on fuel forms were continued with CeF_3 and CeO_2. SiC_2 appeared to be the most promising addition to CeO_2 Tests showed that the Allegheny Ludlum alloy S-818 alloy is resistant to attack by CeO_2 and CeF_3, but is attacked by Ce metal. Hazards Analysis. Analyses of launch abort impact zones for the open core and of aerodynamic burnup for near orbital injection on two types of Mo fuel cores continued. Manufacturing. Fabrication and assembly of the first electrically heated generator was completed System and Component Test. It was found that lead telluride couples increased in resistivity after heating to 1000°F and masked resistivity changes because of radiation. Inconel X cores were heated to approximately

1500°F and impacted on either granite or water targets. All of the cerium-metal loaded cores ruptured. Cores loaded with lavite pellets were recovered intact. Heat transfer mockup tests were completed with a revised two-layer stainless steel heat shield. SNAP-III. The 3M1G3 thermoelectric generator was repaired and parametric testing resumed. The power output of the second SNAP-III unit was measured and proof of thermoelectric generator operation for at least a period of a year was demonstrated. SNAP-IIIA. The performance characteristics of a second SNAP-IIIA generator of completely new design were only marginally better than the original. Tests were performed on metal-encased and ribbon-emitter types of tubes. A wire-wound ceramic heater and a tungsten-wire radiation heater were fabricated and tested. Work was continued on the molybdenum collector used in conjunction with a Type B impregnated tungsten emitter. Low Power Thermionic Generator. Work on improved heat transfer between the emitter holder and the heat source revealed that a layer of Mo powder between the two surfaces gives a lower film drop and more consistent results. Creep tests on sapphire spacers (Al_2O_3) showed that some creep takes place above 1200°C, and above 1300°C, the strength of the sapphire falls off rapidly. A device for measuring the thermal expansion of CeO_2 fuel pellets while in a hot cell was fabricated. Thermoelectric 2- to 5-Watt Generator. Altitude chamber tests of the generators were successfully completed. A shock-wave test proved the capsule can survive missile propellant detonation. Power output versus time plots were developed for both the cerium- and polonium-fueled systems.

46 **(MND-P-3012-II) SNAP PROGRAMS. Quarterly Progress Report No. 4 [for] July 1 through September 30, 1960. Subtask 5.3 and Task 6. R. Harvey and W. M. Bowes, eds. (Martin Co. Nuclear Div., Baltimore). 170p. Contract AT(30-3)-217. OTS.**

Generator 2A, the design of which was completed last quarter, was fabricated and electrically tested. The generator met all significant design requirements with the exception of the collector work function. During the preparations for environmental tests one of the leadthroughs failed. Metallographic examination revealed that it is necessary to make some design revisions of the leadthrough. Generator 2A was an experimental unit which led to the design of generator 2B. Specifically, the conclusions obtained from 2A confirmed certain processing methods applicable to future units. The latter unit includes provisions for remote control fueling, and its operation should attain anticipated performance characteristics (P_o, η, w, ϕ_c, T_e, T_c and life). Critical areas of design, construction, and processing of 2B include the facility for remote control fueling, the attainment of close interelectrode spacing and low collector work function, and the achievement of a rugged generator. Accordingly, a vigorous theoretical and experimental approach was undertaken. A life test on generator 1A was initiated and over 2100 hr of operating time was accumulated. The emitter was not aged prior to incorporation into the generator; as a result, the evaporation of barium from the emitter eventually reduced the diode internal resistance to the point where it was no longer feasible to continue the life test. The procedures for fueling a thermionic generator with a Cm^{242} heat source were established. An activation device in which a work function of approximately 1.9 volts was achieved was designed, fabricated, and tested. These same techniques can be incorporated in a practical generator design. Following this test, the preliminary design of generator 2B was established, and development on the design was initiated. To date, considerable progress has been made in the development of purification processes for gram quantities of americium and curium. Design, fabrication, and installation of experimental equipment for producing capsules for irradiation, for processing the capsules after irradiation, and for testing containment materials has been completed, and the equipment is in operation. The processes involved are being rigorously evaluated in preparation for the construction of prototype systems. Nuclear, thermal, and hazards analyses were undertaken on all phases of this task; results appear quite satisfactory. (For preceding period see MND-P-3011.)

47 (MND-P-3013-II) SNAP PROGRAMS. Quarterly Progress Report No. 5, October 1—December 31, 1960. (Martin Co. Nuclear Div., Baltimore). Contract AT(30-3)-217. 138p.

The procedure for fueling a thermionic generator with Cm^{242} heat source was evaluated. Aspects stressed in development of generator 2B include generator ability to withstand statement of work specified dynamic loads, interelectrode spacing reduction, collector work function reduction, and heat loss reduction. A collector work function of 2.0 volts was achieved at 900°K in an activation test unit built to observe heat transfer between heater and emitter. Fuel technology development was centered around Cm^{242} and Pu^{238}.

48 (MND-P-3015-I) SNAP RADIOISOTOPE SPACE PROGRAMS; TASK 7. Quarterly Progress Report No. 7, April 1 through June 30, 1961. (Martin Co. Nuclear Div., Baltimore). Contract AT(30-3)217. 41p.

Safety analyses of the launch of SNAP-type units as to launch, ascent, and intermediate or final-stage failures are reported. A preliminary design study to define the configuration and performance of the Surveyor generator is completed. Dispersion patterns are found for radioactive materials released by the high-velocity vertical impact of Surveyor-type generators on the moon. High-velocity testing methods are discussed. Flare and telemetry capsules, designed to simulate fuel cores of nuclear auxiliary power systems in Atlas-type ballistic re-entry trajectories, are in final production stages. The design of a SNAP-3 test generator is completed. Analytical studies are reported on the diffusivity of various particle sizes and on the ablation phenomenon as it pertains to re-entry of radioisotope fuels. A preliminary flare and telemetry capsule test is discussed. Routine coding, assembly, and checkout operations are carried out on radioisotope shielding codes. Arrangements are made to obtain code input information and actual radiation levels from the Sr^{90}-fueled weather station generator, as a check problem to verify code calculation results.

49 (MND-P-3016-I) SNAP RADIOISOTOPE SPACE PROGRAMS. Quarterly Progress Report No. 8, Task 7, July 1 through September 30, 1961. (Martin Co. Nuclear Div., Baltimore). Contract AT(30-3)-217. 50p.

Activities in a program devoted to the safety evaluation of isotopic power systems in space applications are reported. In the study of upper atmosphere re-entry, flare and telemetry test capsules were completed for scheduled re-entry tests. The altitude of re-entry burn-through for all phase I and II test capsules and nose cone-vehicle-pod relative position data were determined. These data were used in determining the optimum positions and headings for the optical and optical-telemetry aircraft. A 100-lb test pod containing simulated SNAP 3 fuel cores was shot into space in July 1961. Two of these were flare capsules containing Na and K, and one was a telemetry capsule containing a transmitter. The flares were sighted and a telemetry signal was received in this test. The high altitude diffusion and dispersion study was concluded with the writing of equations for turbulence-induced cloud growth, wind-induced translational motion and gravity-induced vertical motion. Results of the program for predicting fuel particle size as a function of initial size and re-entry velocity and altitude are included. Work on the radioisotope shielding code was continued.

50 (SC-DC-3553(p.91-102)) SAFETY OF ISOTOPIC SNAP GENERATORS. W. Hagis and D. G. Harvey (Martin-Marietta Corp. Aerospace Div., Baltimore).

The SNAP-3 and TRANSIT-4A generators are used in illustration of safety requirements. The factors considered are the type and fuel inventory of the isotope selected, the method of placing the power system into orbit and the replacement rate, the mission, altitude, and orbital inclination of the satellite, and the period in which the systems are to be used and the technology involved in experiments performed during this time.

51 TID-7571(p.27-38)
Martin Co. Nuclear Div., Baltimore.
RADIOISOTOPES AS SOURCES OF ELECTRICAL POWER. Jerome G. Morse. 12p.

Radioisotopes, particularly fission products, are under investigation as sources of electricity. The decay heat, resulting from the absorption of particulate and electromagnetic radiations in suitable containment, may be converted into electricity using such energy conversion devices as thermoelectric generators. Advantages and disadvantages of using radioisotopes as energy sources are reviewed. SNAP-III, fueled with polonium-210, is described and its performance characteristics are noted. The approach to using strontium-90 in small, remote land-based power plants is described. Potential applications of SNAP-III type devices are listed.

52 NUCLEAR SAFETY ANALYSIS OF SNAP III FOR SPACE MISSIONS. W. Hag·s, T. Dobry, and G. Dix (Martin Co., Baltimore). ARS (Am. Rocket Soc.) J., 31: 1744-51(Dec. 1961).

Snap III is an auxiliary power source using thermoelectric elements to convert decay heat from a radioisotope directly into electrical energy. The fate of the radioisotope fuel in the event of post orbital re-entry after a successful satellite mission or an abort during a launch attempt was investigated. The objective was to determine the locations of impact or the locations and altitudes of the radioisotopic fuel capsule during burnup that could result from all possible combinations of final stage booster thrust, misalignments, or failures. Burnup altitude for a post orbital re-entry was also determined for a 275-mile circular orbit. The safety of the mission was appraised with respect to the fate of the radiopolonium fuel for successful missions and for the spectrum of potential aborted missions. Seven general cases resulted from the 65 abort cases examined. Concurrent with the theoretical investigation, a safety experimental program was conducted. These tests involved both missile failure and aerodynamic forces. They included plasma jet, impact, shock, fire, and fallout tests. The results indicate that the Snap III would be acceptable for operational missions. The deposits resulting from dispersing the radioactive fuel during re-entries, from either successful or aborted missions, would be completely masked by the Po^{210} that is naturally present in soils all over the world.

53
SNAP III—ELECTRICITY FROM RADIONUCLIDES AND THERMOELECTRIC CONVERSION. Melvin Barmat (Martin Co., Baltimore); G. M. Anderson (U. S. Atomic Energy Commission, Germantown, Md.); and E. Wayne Bollmeier (Minnesota Mining and Mfg. Co., St. Paul). Nucleonics 17, No. 5, 166-8; 171-2; 174(1959) May.

A demonstration model of a radionuclide battery is described. It is designed to generate electrical power from the heat of radioactive disintegration. The model consisted of a small central heat source containing 1,760 curies of Po^{210}, 54 semiconductor thermoelectric elements, and an outer shell designed to radiate heat to full space. The characteristics of a full-scale device are tabulated.

54
DESIGN AND PERFORMANCE CHARACTERISTICS OF SNAP-III-B. Presented at Nuclear Engineering and Science Conference, April 6-9, 1959, Public Auditorium, Cleveland, Ohio. Preprint V-132. Melvin Barmat (Martin Co., Baltimore). New York, Engineers Joint Council, 1959. 24p. $0.50.

The design philosophy and problems met during the construction of the first two radioisotope-fueled thermoelectric generators by the Martin Nuclear Division under the SNAP-III program are discussed. Besides detailing the original specifications, the most up-to-date information on the actual performance of the unit that was available on April 6, 1958, is included.

55 ISOTOPIC FUELED THERMIONIC GENERATORS Robert J. Harvey (The Martin Co., Baltimore, Md) and G N. Hatsopoulos p 409-41 of "Ballistic Missile and Space Technology Vol II." New York, Academic Press, 1960.

The progress of the thermionic generator phase in the SNAP-3 program is outlined. The advantages of the close-spaced vacuum diode over the cesium plasma diode are discussed, the vacuum diodes are usable over a wide power range, whereas the cesium devices would be limited to special applications. The performance of a vacuum diode thermionic converter is analyzed, thermal efficiency, radiation heat transfer, electron cooling, heat losses, and optimum efficiency are considered. Optimum characteristic design charts were computed for a family of diodes having a spacing of 0 001 cm, a collector work function of 1.85 v, and a collector temperature of 900°K The criteria for choosing the isotope as the heat source are discussed, a study of the available isotopes shows only two isotopes to be suitable for thermionic generators, Cm^{242} and Pu^{238}. A two-stage electrically heated generator was built and tested electrically and dynamically (acceleration and vibration tests), and some of the results are reported

Mound Laboratory, Miamisburg, Ohio

56 (MLM-1127) NUCLEAR BATTERY-THERMOCOUPLE TYPE SUMMARY REPORT. B. C. Blanke, J. H. Birden, K. C. Jordan, and E. L. Murphy (Mound Lab., Miamisburg, Ohio). Oct. 1, 1960. Contracts AT(33-1)-GEN-53 and R-65-8-99811-SC-03-91. 68p.

The potential usefulness of approximately 1300 radioactive isotopes as a heat source for the thermoelectric generator was investigated. Only 47 were found to have the proper characteristics of high specific activity and usable half-life combined with an easily absorbable radiation. These isotopes are discussed showing possible sources of supply, the hazards involved, and the expected performance. Three large Po^{210} heat sources were designed and constructed (for battery use), including one for the SNAP III generator. One small Tl^{204} test heat source was made by irradiation. Eight thermoelectric generators were developed and two of these were used as thermoelectric batteries. Theoretical equations for non-semiconductor thermoelectric materials and experimental measurements to verify the Thompson and Peltier effects are given

Miscellaneous

57 PERFORMANCE DATA AND ENVIROMENTAL TEST RESULTS OF SNAP III. Fred N. Huffman and Louis W. Gross. Planetary Space Sci., 4 226-41(1961).

Performance data and environmental test results on the polonium-fueled SNAP III thermoelectric generator for satellite power are described. Although one may squeeze five watts out of the generator in room ambient conditions, it is a 2.5 w unit in a space environment. The electrical performance data and the vibration, acceleration, and shock results indicate the feasibility of using the generator for extending the useful life of satellites. Curves are given of its performance along with a description of the generator.

SNAP—7

(See also references 18, 283)

General Instrument Corporation, Thermoelectric Division, Newark, New Jersey

58 (NYO-10462) ECONOMIC FACTORS OF MFP THERMOELECTRIC GENERATORS Final Report E J Lemanski (General Instrument Corp Thermoelectric Div Newark, N J) May 1963 Contract AT(30-1)-2605 40p

Economic aspects of power generation from underwater thermoelectric generators fueled with Mixed Fission Products (MFP) are given Costs are estimated to be less than $0 15 per thermal watt for two year old MFP Studies are on a conceptual design of a unit capable of withstanding pressures equivalent to 18,000 feet submergence on the ocean bottom and 300 year containment of the nuclear heat source Low cost biological shields of both high density concrete and cast iron were considered Studies establish the possibility of power costs as low as $10 per watt-year in the kilowatt size, to $100 per watt-year in the 10 watt range A comparison of the MFP generator with an equivalent SNAP-7 strontium-90 type indicates that the MFP power costs are far below those for separated radioisotope power, primarily because the highest cost item in the SNAP unit is the purified strontium-90 fuel A one kilowatt MFP unit would weigh in the order of 20 to 30 tons maximum depending on fuel energy density, and have a diameter of 6 to 10 feet Optimization studies were made for such factors as fuel geometry, fuel age, energy density and insulation thickness to determine the most productive areas of reducing the original cost and overall weight estimates

Martin-Marietta Corporation, Aerospace Division, Baltimore, Maryland

59 SNAP-7A, 7B, AND 7D (Engineering Materials) (Martin Co Nuclear Div , Baltimore). 8 drawings (CAPE-937)

These Systems for Nuclear Auxiliary Power use heat that is produced by the decay of Sr^{90} to generate electricity in thermoelectric converters SNAP-7A and 7B are 5- and 30-w respectively, thermoelectric generators used by the U S Coast Guard in operating lighted marine aids to navigation Converters and generators supply 10 and 60-w. SNAP-7C and 7D are also 5- and 30-w power supplies used by the U S Navy to provide power for unmanned, remote, automatic weather stations The systems operate without moving parts

60 (MND-P-2483-1) TASK 8—STRONTIUM-90 FUELED THERMOELECTRIC GENERATOR DEVELOPMENT SNAP Programs Quarterly Progress Report No 1, November 1, 1960 through January 31, 1961 W S West (Martin Co Nuclear Div , Baltimore) Contract AT(30-3) 217 78p

Design and engineering analysis data are presented for four SNAP-7 Sr^{90}-fueled thermoelectric generators of 5- and 30-watt power Fuel process flow and associated equipment requirements for remote conversion of Sr^{90} feed material to $SrTiO_3$ pellets are given together with fuel specifications

61 (MND-P-2483-2) SNAP PROGRAMS, TASK 8—STRONTIUM-90 FUELED THERMOELECTRIC GENERATOR DEVELOPMENT Quarterly Progress Report No 2, February 1, 1961 through April 30, 1961 W West (Martin Co Nuclear Div , Baltimore) Contract AT(30-3)-217 135p

Work in the processing of Sr^{90} into heat sources for 4 radioisotope-fueled thermoelectric power generation systems is described The design and engineering analysis of these thermoelectric generators are discussed Fuel process flow and associated equipment requirements for remote conversion of Sr^{90} feed material to strontium titanate pellets are covered Previously evolved technical standards concerning raw fuel material specification were coordinated

62 (MND-P-2483 3) SNAP 7 PROGRAM, TASK 8—STRONTIUM-90 FUELED THERMOELECTRIC GENERATOR DEVELOPMENT Quarterly Progress Report No 3, May 1, 1961 through July 31, 1961 W West (Martin Co Nuclear Div , Baltimore) Contract AT(30-3)-217 44p

The SNAP 7 program is being conducted for the purpose of developing 4 radioisotope fueled thermoelectric power generation systems An important phase of this program is the processing of Sr^{90} into heat sources for these systems The thermoelectric reliability breadboard model and the operating model of the 10-watt thermoelectric generator were assembled and prepared for tests The SNAP 7B and 7D 60-watt thermoelectric generators were designed, materials were received, and fabrication of components was initiated Fuel process engineering, nuclear chemistry audit, and manufacturing fuel processing equipment achievements are discussed.

63 (MND-P-2483-4) SNAP 7 PROGRAM TASK 8—STRONTIUM-90 FUELED THERMOELFCTRIC GEN-

ERATOR DEVELOPMENT. Quarterly Progress Report No 4, August 1, 1961 – October 31, 1961. W. S West (Martin-Marietta Corp. Aerospace Div., Baltimore). Contract AT(30-3)-217. 108p.

Progress during the period includes completion of the SNAP 7C system tests, completion of safety analysis for the SNAP 7A and C systems, assembly and initial testing of SNAP 7A, assembly of a modified reliability model, and assembly of a 10-W generator. Other activities include completion of thermal and safety analyses for SNAP 7B and D generators and fuel processing for these generators

64 (MND-P-2483-5) SNAP 7 PROGRAM—TASK 8—STRONTIUM-90 FUELED THERMOELECTRIC GENERATOR DEVELOPMENT Quarterly Progress Report No 5, November 1, 1961 to January 31, 1962. W. A. McDonald (Martin Co. Nuclear Div., Baltimore). Contract AT(30-3)-217. 41p

The SNAP 7A battery and converter were subjected to the required shock, vibration and temperature tests. The generator was fueled, postfueling radiation levels were checked and the generator was integrated into the complete SNAP 7A system After the completion of acceptance tests, the SNAP 7A system was installed in a buoy which, in turn, was anchored in the bay where it will be subjected to further evaluation. The SNAP 7C generator was shipped for transport to Antarctica. The generator will power a five-watt U. S. Navy remote weather station. Tests were also conducted to determine the operational characteristics of SNAP 7B and 7D thermoelectric couples. Also, the reliability model of the generator was operated at high temperature for 23 days. The electrical, converter and battery specifications for the SNAP 7D system were completed and released. The primary effort in the fuel processing phase of the program was to provide the necessary liaison with the personnel installing the processing equipment. Maintenance and checkout guides were written to assure satisfactory installation and continued performance throughout the fuel processing span. An operation procedure guide was written to describe the engineering concept of the fuel processing operation. The guide was written for the personnel who will be conducting the fuel processing operation.

65 (MND-P-2483-6) SNAP 7 PROGRAM—TASK 8—STRONTIUM-90 FUELED THERMOELECTRIC GENERATOR DEVELOPMENT. Quarterly Report No. 6, February 1 through April 30, 1962. W. A. McDonald (Martin Co. Nuclear Div., Baltimore). Contract AT(30-3)-217. 26p.

Manufacture, assembly, and parametric testing of the first 60-watt thermoelectric generator were completed. All of the Sr-90 fuel process equipment was installed. Equipment checkouts and process dry runs have indicated a number of problems. The problems will probably cause a slight delay in hot operation; however, it is expected that schedule commitments in completing the fuel for the SNAP-7B system will be met. The power output of the Coast Guard SNAP-7A system is decreasing much faster than anticipated. A comparison of power output and hot and cold junction temperature readings with parametric operational data shows that the generator is performing as predicted. A plot of the decay in hot junction temperature (cold junction temperature approximately constant) indicates that the isotope fuel had too much Sr-89 and, therefore, too little Sr-90. Restoration would consist of changing the high conducting inert gas, helium, to a mixture of helium and argon which has better thermal insulating properties.

66 (MND-P-2483-7) SNAP 7 PROGRAM—TASK 8—STRONTIUM-90 FUELED THERMOELECTRIC GENERATOR DEVELOPMENT. Quarterly Progress Report No. 7, May 1 through July 31, 1962. W. A. McDonald (Martin-Marietta Corp. Aerospace Div., Baltimore). Contract AT(30-3)-217. 20p.

The effort on SNAP 7A and 7C was confined to operating the reliability model. There were fluctuations in output power that can be attributed to variations in the operating parameters, plus an increase in the internal resistance. In the SNAP 7B project the second 60-watt generator was completed and has undergone the beginning-of-life (maximum input, helium gas) portion of the parametric tests. The performance was nearly identical to that of the first 60-watt generator. The unit will be used with the SNAP 7B system. The installation concept for the SNAP 7B system was approved by the U. S. Coast Guard. The generator is to be housed in a finned aluminum container that will provide the required radiator surface. This container will be filled with a water-ethylene glycol mixture that is necessary to transfer the heat from the generator into the container. The battery-converter compartment is an integral part of the container lid. During the time the entire SNAP 7D system was subjected to shock and vibration tests, no mechanical or functional deficiencies were detected. The required temperature tests followed the mechanical tests. During this period the complete system was operated at maximum intermediate and minimum temperatures. Design objectives were satisfied throughout the test The SNAP 7D generator was fueled at Oak Ridge National Laboratory (ORNL) on June 12, 1962, with a total thermal input of 1435 watts The fueled generator was returned and integrated with the system. The system was demonstrated and accepted on July 3, 1962.

67 (MND-P-2613) FINAL SAFETY ANALYSIS, TEN-WATT STRONTIUM-90 FUELED GENERATOR FOR AN UNATTENDED LIGHT BUOY, SNAP-7A. (Martin Co. Nuclear Div., Baltimore). [1961]. Contract AT(30-3)-217. 51p.

The results are presented of a safety analysis of a prototype strontium-90 fueled generator. The fuel capsules produce 256.5 watts(t), from the decay energy, which is converted to 10 watts(e), with a 5 watt net output from the batteries. The generator can be safely transported and operated with normal precautions afforded any structure containing a radioisotope. The shielding provided is adequate for protection against direct radiation exposure. The integrity of the system is maintained under most conceivable accident conditions.

68 (MND-P-2614) FINAL SAFETY ANALYSIS, TEN-WATT STRONTIUM-90 FUELED GENERATOR FOR AN UNATTENDED METEOROLOGICAL STATION SNAP-7C. Phillip M. Brooks (Martin Co Nuclear Div , Baltimore). [1961]. 51p

The analysis indicated that the generator can be safely transported and operated with the normal precautions afforded any structure containing a radioisotope. The shielding provided for protection against direct radiation exposure is considered adequate. Integrity of the system is maintained under most conceivable accident conditions The insolubility and chemical stability of the radiostrontium titanate is incidental as long as containment is maintained.

69 (MND-P-2640) INSTRUCTION MANUAL—SNAP-7C ELECTRIC GENERATION SYSTEM. [E Blazek] (Martin Co. Nuclear Div., Baltimore). Oct. 1, 1961. Contract AT(30-3)-217. 60p.

A description of SNAP-7C isotope-fueled electric generation system is presented. The operational limits and transportation, handling, installation, and adjustment procedures are described Maintenance instructions and emergency and safety precautions are included

70 (MND-P-2707) STRONTIUM-90 FUELED THERMOELECTRIC GENERATOR POWER SOURCE—FIVE-WATT U S NAVY WEATHER STATION Final Report (Martin-Marietta Corp Aerospace Div , Baltimore) [nd] Contract AT(30-3)-217 127p

The SNAP-7C 10-watt Sr^{90} thermoelectric generator, the converter, batteries, and weather station housing that were delivered to Antarctica in December 1961 are described Thermoelectric analysis, thermal analysis, fuel form and shielding requirements, generator assembly, electrical system, operational tests, and environmental testing are discussed

71 (MND-P-2720) STRONTIUM-90 FUELED THERMOELECTRIC GENERATOR POWER SOURCE FOR FIVE-WATT U. S. COAST GUARD LIGHT BUOY. Final Report. (Martin Co. Nuclear Div., Baltimore). Feb. 2, 1962. Contract AT(30-3)-217 140p.

The objectives of the SNAP 7A program were to design, manufacture, test, and deliver a five-watt electric generation system for a U. S. Coast Guard 8 × 26E light buoy. The 10-watt Sr^{90} thermoelectric generator, the d-c-to-d-c converter, batteries and the method of installation in the light buoy are described. The SNAP 7A generator was fueled with four capsules containing a total of 40,800 curies of Sr^{90} titanate. After fueling and testing, the SNAP 7A electric generating system was installed in the Coast Guard light buoy at Baltimore, Maryland, on December 15, 1961. Operation of the buoy lamp is continuous.

72 (MND-P-2761) FINAL SAFETY EVALUATION OF A TEN WATT STRONTIUM-90 FUELED GENERATOR FOR A DEEP SEA APPLICATION—SNAP 7E H N Berkow and V. G Kelly (Martin Co Nuclear Div , Baltimore). May 1962. Contract [AT(30-1)2958]. 51p.

A safety evaluation of the SNAP 7E thermoelectric generator system is described. Analyses were performed to assess the radiobiological effects in event of a fuel release and the shielding was evaluated to determine the safe working limits for personnel. The entire evaluation is based on a fuel loading of 31,000 curies of radiostrontium It is concluded that the safety criteria are met and there is reasonable assurance that this generator is safe for its intended mission.

73 (MND-P-2835) SNAP 7D—STRONTIUM-90 FUELED THERMOELECTRIC GENERATOR POWER SOURCE. THIRTY-WATT U. S. NAVY FLOATING WEATHER STATION. Final Report. C. N. Young (Martin-Marietta Corp. Aerospace Div , Baltimore). Mar. 15, 1963. Contract AT(30-3)-217. 102p.

The objectives of the SNAP-7D program were to design, manufacture, test and deliver a thirty-watt electric generating system for a modified U. S. Navy NOMAD-class weather buoy to be stationed in the Gulf of Mexico The sixty-watt Sr^{90} thermoelectric generator, the relay panel, the batteries, and the installation of the system in a boat-type buoy are described. In addition to delivering the power supply, many tests were required for the SNAP-7D system to demonstrate its conformance to the contract statement of work. The electrical tests of the generator and of the system, the shock and vibration tests, and the tests at the environmental temperature extremes are discussed.

74 (MND-P-2836) SNAP 7B—STRONTIUM-90 FUELED THERMOELECTRIC GENERATOR POWER SOURCE THIRTY-WATT U S COAST GUARD AUTOMATIC LIGHT STATION Final Report (Martin-Marietta Corp Aerospace Div , Baltimore) June 1963 Contract AT(30-3)-217 102p

The objectives of the SNAP 7B program were to design, manufacture, test and deliver a thirty-watt electric generating system for a U S Coast Guard Automatic Light Station This report describes the sixty-watt, strontium-90 thermoelectric generator, the converter, the batteries, and the installation of the generator into the container The electrical tests of the generator and of the system, the shock and vibration tests, and the tests at the environmental temperature extremes are discussed

75 (MND-P-2977) PRODUCTION OF STRONTIUM—TITANATE RADIOISOTOPE FUEL FOR SNAP 7B THERMOELECTRIC GENERATOR. Justin L Bloom (Martin-Marietta Corp. Aerospace Div , Baltimore) Apr 15, 1963 Contract AT(30-1)-3062 92p

The conversion of strontium-90 to strontium titanate heat source pellets is described Encapsulation of the fuel in Hastelloy C containers and necessary leak testing, decontamination and calorimetry procedures are covered Loading of the SNAP 7B thermoelectric generator was accomplished

76 (MND-SR-2428) DATA TELEMETRY PACKAGE POWERED BY A STRONTIUM-90 GENERATOR (Martin Co Nuclear Div , Baltimore) Sept 30, 1960 Contract AT(30-1)-2519 142p

Work accomplished on design and fabrication of an automatic, nuclear-powered, remote meteorological data transmitting radio station and equipment for a manned receiving station is reported Two years of continuous unattended operation is the primary aim of the design Work on the Sr^{90} thermoelectric generator includes design, fabrication, and electrical test of a 5-W system and coordination of the Sr^{90} loading with ORNL

77 PRODUCTION OF STRONTIUM-90 THERMAL POWER SOURCES A Schneider, J. L Bloom, and J S. Cochran (Martin-Marietta Corp Aerospace Div , Baltimore) IAEA Preprint No CN-14/22. 31p (TID-18761)

To be published in IAEA Proceedings of the Conference on the Application of Large Radiation Sources in Industry, held in Salzburg, Austria, May 27–31, 1963

One of the most attractive areas for utilization of large quantities of waste fission products was demonstrated to be in the field of direct conversion power supplies for remote locations Sr^{90} is being given the greatest exploitation because of its availability, nuclear properties, and the relative ease with which it can be fabricated into compact heat sources Sr^{90}-fueled generators are being used to power automatic weather stations and navigational aids, and consideration is being given to the use of Sr^{90} as a power source for space vehicles. Evaluation of several potentially useful strontium compounds led to the selection of the titanate as exhibiting over-all properties most desirable for this purpose Sr^{90}, separated from crude fission product streams and purified to the requisite degree, is shipped in the form of the carbonate to a hot-cell facility, where it is converted to titanate pellets This process is an adaption to remote operation of conventional chemical and ceramic techniques The pellets are encapsulated in Hastelloy C containers for use in thermoelectric power supplies Unusual operational problems are encountered because the large quantities of Sr^{90} handled (potentially millions of curies per year) represent formidable radiation and contamination hazards. Details of the facility, equipment, process, and safety criteria are given. The operational experience gained during the recent processing of the first 250,000 curies of Sr^{90} into fuel for a SNAP-7 generator is described. Encapsulation, calorimetry decontamination, and waste-disposal procedures are also outlined.

78 Sr^{90} POWERS AN AUTOMATIC WEATHER STATION Wilfred L. Kershaw (Martin Co., Baltimore). Nucleonics, 20 No 11, 92, 94, 96-7 (Nov. 1962).

The development of the first nuclear-powered weather system, now in operation on Axel Heiberg Island in the Arctic, is described. $SrTiO_3$ and Hastelloy C were selected as the Sr^{90} compound and container material, respectively, and a 5-watt thermoelectric generator and a data telemetry package were constructed. Test results and installation are described.

Miscellaneous

79 ISOTOPIC POWER DEVELOPMENT. p.89-96 of "Isotopes and Radiation Technology. Vol. 1, No. 1."

A survey is presented of thermoelectric generators using radioisotopes which were designed for remote-area terrestrial use. The generators described include a 5-watt Sr^{90} generator for a weather station in the Arctic, a 10-watt Sr^{90} generator for a light buoy, a Ce^{144} heat source for water desalination, and a 5-watt Cs^{137} generator for an underwater seismograph. The use of calorimetry at ORNL for measuring the rates of heat production by radioisotopes is discussed, and the design and operation of temperature-gradient calorimeters are described. Applications of calorimetric measurements are considered.

SNAP—9

(See also reference 50)

Air Force, Washington, D. C.

80 INTEGRATING ISOTOPIC POWER SYSTEMS R T Carpenter (Air Force, Washington, D C) and Douglas G Harvey Astronautics, 7 No 5 30-1, 58, 60-1(May 1962)

Some characteristics that cause unique interface problems between the radioisotope-fueled thermoelectric power supply and the space vehicle pay-load are discussed The interface problems discussed are electrical, thermal, and radiative integration The electrical characteristics of Transit 4A generator are shown A circuit diagram is shown for a (d-c)-(d-c) converter along with the power distribution of the converter The radiation dose one-foot from the core of the generator is tabulated for various radioactive fuels

Martin-Marietta Corporation, Aerospace Division, Baltimore, Maryland

81 RADIONUCLIDE POWER FOR SPACE PART 2 ISOTOPE-GENERATOR RELIABILITY AND SAFETY D G Harvey P J Dick, and C R Fink (Martin Co Baltimore) Nucleonics 21 No 4, 56-9(Apr 1963)

The operating experience of SNAP devices in the Transit 4A and 4B satellites is described Only two power excursions were observed which are probably due to a capacitor failure in the power conditioning system The results and tests indicate that the reliability of the generator unit and thermoelectric couples will be satisfactory Exhaustive proof testing has shown that containment of the radioactive fuel can be absolutely guaranteed during the launch and that the fuel will burn up on re-entry at orbital velocities The possibility of only partial burnup at suborbital velocities is an improbable one

82 RADIOISOTOPE POWER SYSTEM OPERATION IN THE TRANSIT SATELLITE P J. Dick (Martin Marietta Corp , Baltimore) and R E. Davis Preprint Paper No. CP 62-1173. New York, American Institute of Electrical engineers, 1962 11p $1 00

Day-to-day telemetry readout of stabilized radioisotope-powered generator load voltage from the Transit 4B satellite shows that early thermoelectric system mortality does not occur and that sun-to-shade generator surface temperature variations are about 40°F The application of a closely matched, input-regulated, step-up voltage converter in conjunction with the radioisotope power supply (RIPS) also shows that multiple voltages can be supplied to the electronic packages while maintaining conversion efficiencies in the range of 70 to 85% By use of converter output filters, voltage ripple can be held below 0 5% and radiofrequency interference is essentially eliminated

Sandia Corporation, Albuquerque, New Mexico

83 (SC-DC-3248) AEROSPACE NUCLEAR SAFETY GROUND TEST PROGRAM J L Colp (Sandia Corp , Albuquerque, N Mex) [Sept 1963] Contract AT(29-1)-789 20p (CONF-311-1)

From American Nuclear Society Aerospace Nuclear Safety National Topical Meeting Albuquerque, N Mex , Oct 1963

The assessment (by ground testing) of effects of mechanical actions, thermal and chemical interactions, and nuclear reactions upon the safety of nuclear power sources that are intended for aerospace applications is discussed Progress in general studies and in testing of SNAP-9A and -10A is reviewed

NAP—100

Westinghouse Electric Corporation, New Products Laboratory, Cheswick, Pennsylvania

84 (AFSWC-TDR-61-99) NAP-100 THERMOELECTRIC GENERATOR REPORT. G Spira and T. M. Corry (Westinghouse Electric Corp. New Products Labs., Cheswick, Penna.). Nov. 1961. Contract AF30(602)-1875. 38p. (AD-274280)

The development and performance are presented of a 100-w isotopic fuel, thermoelectric generator designated NAP-100 (Nuclear Auxiliary Power). The generator unit was treated as an integrated system to minimize size and weight without undue sacrifice in efficiency. The 3 basic elements of the generator are (1) the cold side convective heat exchanger, (2) the thermoelectric couple assembly, and (3) the heat source (an electrical heater which simulated the thermal performance of the nuclear heat source was designed and delivered with the generator).

REACTOR UNITS

SNAP—2

(See also references 215, 223, 224, 234, 319)

Air Force Systems Command, Los Angeles, California

85 ORBITAL TESTING OF SNAP SYSTEMS George E Austin (Air Force Systems Command, Los Angeles) Astronaut Aerospace Eng , 1 No 4, 37-42(May 1963)

Objectives to be accomplished in orbital testing of Snap-2 and Snap-10A are outlined The ability of vehicle components and subsystems to survive in the radiation environment, mechanical thermal and electrical interface problems unique to the utilization of nuclear power, and radiological safety precautions and procedures to be established in the orbital testing of Snap systems are discussed

Atomic Energy Commission, Washington, D. C.

86 NUCLEAR REACTOR SYSTEMS G Montgomery Anderson (Atomic Energy Commission, Washington, D C) Astronaut Aerospace Eng , 1 No 4, 27-36(May 1963)

The objectives of the orbital flight tests of the Snap-2 and Snap-10A are briefly outlined Fundamental criteria for safety throughout all phases of the flight test are given The flight design of the reactor, shield thermoelectric generator, thermoelectric pump, and structure of the Snap-2 and -10A systems are also discussed The performance characteristics of the Snap-2 -8 -10A are presented

Atomics International, Division of North American Aviation, Incorporated, Canoga Park, California

87 (AI 7950) APPLICATION OF SNAP 2 TO MANNED ORBITAL SPACE STATIONS H N Rosenberg ed (Atomics International Div of North American Aviation Inc Canoga Park Calif) Dec 16 1962 90p

The results of a study of the installation and operational characteristics of a SNAP reactor system integrated with a manned space station are presented The reference system selected was an 11 kw(e) version of a SNAP 2 system employing multiple power conversion units coupled to a single reactor source Of prime importance is the reactor radiation shield required for the manned system and the use of design features which minimize the shield weight The weight of the radiation shield is highly dependent upon the geometrical configuration of the space station and the reactor since "shadow" shielding of the manned compartments is required for minimum weight systems The installation and shielding requirements of the 11 kw(e) system were considered for two types of space station configurations one was a 10 ft dia cylindrical station with a reactor separation distance of 50 ft and the other a 150 ft dia toroidal station with the reactor located in the hub The weight of the power system installed in the cylindrical space station was about 9000 lb of which 6000 lb was required for shielding The weight of the system for a toroidal station was ~25 000 lbs of which 20 000 lbs was required for shielding However these weights are relatively insensitive to power level and doubling or tripling the power output will only increase these weights by a small percentage In addition the designs developed for these two concepts permit the replacement of the reactor and power conversion system with the radiation shields becoming essentially a permanent part of the space station Hence the large weight penalty associated with the reactor shield only has to be incurred once during the life of the space station Because of the dominance of the reactor shield weights for manned systems parametric curves of shielding weight are presented to enable the space vehicle designer to estimate nuclear power system weights for configurations other than those selected in this report

88 (BNL-756(p 294-325)) DEVELOPMENT OF SNAP 2 HEAT TRANSFER COMPONENTS W D Leonard and R D Keen (Atomics International Div of North American Aviation, Inc , Canoga Park, Calif)

The development of 6 SNAP 2 heat transfer components is described These are the expansion compensator, the parasitic load heater, the flow trimmer, the orbital start pump, the radiator-condenser, and the auxiliary ground heater Results of system tests are discussed

89 (CONF-311-9) DESIGN AND SAFETY ASPECTS OF HYDRIDE-FUEL SNAP REACTORS D J Cockeram and R L. Detterman (Atomic International. Div of North American Aviation, Inc , Canoga Park, Calif) [nd] 18p Contract AT(11-1)-Gen-8

From American Nuclear Society, Aerospace Nuclear Safety National Topical Meeting, Albuquerque, N Mex , Oct 1963.

The general optimization for the reactor designs using uranium–zirconium hydride (SNAP-10A, 2, and 8) is described. The inherent features which determine the physical characteristics of the system and the safeguards for criticality protection during shipping and handling are discussed.

90 NAA-SR-4762
Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.
MELTING AND FORMING OF SER FUEL RODS. P. S. Drennan. Oct. 1, 1960. 30p. Contract AT-11-1-GEN-8. OTS.

Sixty-one metal alloy rods were fabricated for the SNAP Experimental Reactor (SER), a compact nuclear power source. These rods were 1 in. in diameter by 10 in. long and consisted of an alloy containing 7 wt. % highly enriched uranium and 93 wt. % zirconium. Melting of the alloy was done by generally accepted consumable-arc melting techniques. Extrusion of alloy slugs into rods was carried out, unclad, at 850°F. Suitable controls were developed to insure uniformity of products and reproducibility of batches. The procedures developed for this application are considered adequate for future requirements.

91 (NAA-SR-5244) SNAP 2 REACTOR PUMP DEVELOPMENT PROGRAM (RADIAL GAP PERMANENT-MAGNET PUMP). S. Sudar (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.) Sept. 1, 1961 Contract AT-11-1-GEN-8. 50p

A compact electromagnetic pump utilizing a rotating permanent magnet with radial gap was developed for possible application to the SNAP 2 reactor coolant system. The pump was designed for circulation of NaK at 1000°F and 11.2 gpm with a developed pressure of 3 psi, operation at 40,000 rpm, minimum weight and size, and high reliability. The performance characteristics of four developmental pump models were measured in a 1000°F NaK test loop and compared with design predictions. The capability of the pump design concept was demonstrated, though further development work is needed to meet the SNAP 2 pump requirements A flow capacity of 6.8 gpm of NaK at 1000°F with a developed head of 3 psi with attained at a magnet rotor speed of 40,000 rpm. The weight of this pump is 3 pounds Reasonable agreement was obtained between the actual pump characteristics and the design predictions

92 **(NAA-SR-5317) THE SNAP 2 RADIATIVE CONDENSER ANALYSIS. M. G. Coombs, R. A. Stone, and T. Kapus. Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif. [1960]. 63p. Contract AT-11-1-GEN-8. OTS.**

The SNAP-2 power system employs a direct-condensing radiator. In this system, the heat released in the condensation process is radiated to space from a large extended surface, consisting of fins attached to tubes containing the condensing fluid. Aspects of the radiator-condenser design are discussed relative to two-phase flow, heat transfer (condensing, tube to fin, and radiant), meteoroid protection, and reactor-radiator configuration. A procedure is developed for determining a minimum weight heat rejection system based on the optimum data determined analytically

93 (NAA-SR-5619) PHYSICS MEASUREMENTS ON THE SNAP EXPERIMENTAL REACTOR (SER). F. H. Clark, S. G. Wogulis, and M. V. Davis (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.). Jan. 30, 1961. 37p. Contract AT-11-1-GEN-8.

Prior to operation of the SER at temperature and power and with NaK coolant present, a series of measurements were performed in the neighborhood of room temperature and at powers of 1 watt or less. These measurements were designed to establish the characteristics of the system under controlled conditions and to determine safe operating procedures. Measurements were made to determine critical mass in various reflector configurations, control drum and safety element worth, flux mappings in the reactor and importance mappings external to the reactor, reactivity coefficients of various materials, and kinetic parameters. The most important conclusion drawn is that the system as designed has the necessary reactivity and control for its anticipated operation. Full feasibility determinations must necessarily wait upon the outcome of experiments at power and temperature.

94 (NAA-SR-5991) PRELIMINARY RESULTS OF THE SNAP 2 EXPERIMENTAL REACTOR. M. W. Hulin and J. Beall, eds. (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.). Apr. 1, 1961. Contract AT(11-1)-GEN-8. 60p.

The operating history of the SNAP 2 Experimental Reactor (SER) and the preliminary results from the testing program are presented. The total energy generated during the life of the reactor was 224,650 kilowatt hours. This is equivalent to approximately one-half year of full-power operation. The methods used to obtain the reactor parameters are also described. The experimental data obtained were generally in excellent agreement with calculated values The principal comparisons are tabulated.

95 (NAA-SR-6047) THERMAL EXPANSION OF SNAP MATERIALS. J. D. Watrous (Atomic International. Div. of North American Aviation, Inc., Canoga Park, Calif.). July 30, 1961. Contract AT(11-1)-GEN-8. 19p.

Thermal expansion characteristics were determined for the fuel-moderator, reflector, cladding, and engineering materials within the SNAP-2 core vessel. Values were determined for AISI Type 347 stainless steel, Hastelloy N, Be, Zr, ZrH and zirconium–uranium hydrides, from room temperature to temperatures greater than 1300°F. Derived equations were calculated for these materials, using a least squares analysis. Thermal expansion coefficients for the temperature range of 77 to 1200°F are: 10.34×10^{6} in./in./°F, for Type 347 stainless steel; 7.46×10^{-6} in./in./°F, for Hastelloy N; 9.07×10^{-6} in./in./°F, for Be; and 6.12×10^{-6} in./in./°F, for Zr–7 wt % UH with an $N_H = 6.4$.

96 (NAA-SR-6439) SNAP 2 PRIMARY COOLANT DEVELOPMENT. M. A. Perlow (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.) July 15, 1961. Contract AT-11-1-GEN-8. 70p.

The design, development, testing, and selection of components integral to the primary coolant system for the SNAP 2 (Systems for Nuclear Auxiliary Power) reactor for space applications are described. Included are core hydraulic studies, heater (resistance element and transformer types) development, corrosion studies (NaK-78 is the primary coolant), NaK hydride precipitation studies, and lithium hydride (tentatively selected as the SNAP 2 radiation shielding medium) studies.

97 (NAA-SR-7140) TEMPERATURE COEFFICIENTS AND SPECTRA IN THE HYDRIDE MODERATED SNAP REACTORS. J. Miller, R. L. Brehm, and W. J.

Roberts (Atomics International Div of North American Aviation, Inc , Canoga Park, Calif.) Dec 30, 1962 Contract AT(11-1)-Gen-8 56p

A summary of SNAP temperature coefficient measurements accomplished on the SNAP Experiment and Developmental Reactors is presented. Isothermal measurements, transient experiments, and power coefficient measurements are included Analysis of the experiments resulted in isolation of component effects The thermal spectrum temperature coefficient for these zirconium hydride moderated systems is shown to be on the order of −0 04¢/°F. A new model for the energy transfer process in zirconium hydride is presented which reproduces measured spectra and results in temperature coefficients of the magnitude measured. The calculational model is phenomenologically based and uses Fermi-Dirac statistics to describe the state populations of the protons in the zirconium hydride

98 (NAA-SR-7797) SNAP AEROSPACE SAFETY PROGRAM QUARTERLY TECHNICAL PROGRESS REPORT, JULY–SEPTEMBER 1962 (Atomics International Div of North American Aviation Inc , Canoga Park, Calif) Mar 20, 1963 Contract AT(11-1)-Gen-8 56p

Statements are presented concerning project objectives, major accomplishments in FY 1962, progress during the report period, evaluation of effort to date, and next report period activities The subject material covers reactor separation and fuel element ejection, reactor transient and excursion tests, reactor end-of-life shutdown devices, fission product release studies, critical configuration tests, mechanical and thermochemical effects, and fuel element burnup and fission products dispersal Major emphasis for the period was concentrated on the design of the SNAPTRAN 2/10A-1 and -2 machines and the models for the Reentry Flight Demonstration (RFD-1) Planning of the SNAPTRAN experimental program was undertaken Analytical effort was concentrated on developing the several computer codes required for interpreting and understanding the data acquired or to be acquired from the experiments The majority of the Phase I mechanical and thermochemical effects test program was completed A few fission product releases were conducted at the NRTS Necessary test apparatus for the water immersion critical experiment was designed and fabricated

99 (NAA-SR-8097) SNAP AEROSPACE SAFETY PROGRAM Quarterly Technical Progress Report, October–December 1962 (Atomics International Div of North American Aviation, Inc , Canoga Park, Calif) Apr 1, 1963 Contract AT(11-1)-Gen-8 40p

Progress made during the period is reported including analyses of experiments and tests, and evaluation of effort The subject material concerns reactor transient and excursion tests, fission product release studies, end-of-life shutdown devices, critical configuration studies, mechanical and thermochemical effects, reactor separation and fuel element ejection, and reentry burnup of fuel elements The design of the SNAPTRAN 2/10A-1 and -2 machines was essentially completed and fabrication of major components was initiated The fission product release tests at the NRTS were completed Some progress was made on the explosive shutdown projectile design A practical shipping sleeve design was demonstrated which will maintain the SNAP 2/10A assembly in a subcritical condition as a result of postulated shipping accidents The Phase I ground test series were completed The computer code, RESTORE, was shown to be excellent for the calculation of reentry trajectories The calculation of fuel rod heating and ablation using a digital thermal analyzer program resulted in an improved and more elaborate analytical model

100 (NAA-SR-8303) AEROSPACE SAFETY RE-ENTRY ANALYTICAL AND EXPERIMENTAL PROGRAM, SNAP 2 AND 10A (INTERIM REPORT) R D Elliott (Atomics International Div of North American Aviation, Inc , Canoga Park, Calif) Sept 30, 1963 Contract AT(11-1)-Gen-8 69p

Before a reactor is launched into a satellite orbit about the Earth, the hazards to the population must necessarily be considered in the event that the reactor re-enters the Earth's atmosphere and possibly impacts with the ground Analytical and experimental efforts for calculating these potential hazards as they apply to SNAP-2 and -10A are described

101 (NAA-SR-Memo-4796) OPTIMIZATION OF A CONICAL RADIATOR FOR SNAP 2 R A Stone (Atomics International Div of North American Aviation, Inc., Canoga Park, Calif) Dec. 28, 1959 11p

Data are presented on optimization of a conical radiator for SNAP-2 It is noted that the optimum radiator will weigh 95 lbs exclusive of manifold weight, and have a total area of 130 square feet

102 (NAA-SR-Memo-4910) STRUCTURAL PROBLEMS ASSOCIATED WITH DESIGN AND ANALYSIS OF THE SNAP II RADIATOR-CONDENSER H L Sujata (Atomics International Div of North American Aviation, Inc , Canoga Park, Calif) Jan 29, 1960 5p

A suggested program for structural analysis and design of SNAP II radiator-condenser is presented The program is arranged to evaluate vibratory behavior, structural integrity, and thermal load resistance

103 (NAA-SR-Memo-5004) NaK PUMP EVALUATION. R. S. Baker and W. J. Fraser. Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif. Feb. 18, 1960. 30p. OTS.

Four types of electromagnetic pumps were considered, from an efficiency and weight standpoint, for the task of pumping 11 gpm of 78%K NaK having a temperature of 1000°F with a pressure rise across the pump of 4 psi. The d-c conduction electromagnetic pump appeared to be the most suitable. Characteristics of all four types are listed.

104 NAA-SR-Memo-5166
Atomics International Div of North American Aviation, Inc , Canoga Park, Calif
SNAP II REACTOR CORE MATERIALS J V Facha
Apr 11 1960 12p Contract [AT-11-1-GEN-8] OTS

A survey was made to select the construction materials for the SDR-1 reactor core vessel and grid plates Hastelloy C was selected for the reactor vessel, top grid plate, and bottom grid plate Inconel X was selected for the core hold-down springs

105 (NAA-SR-Memo-5302) ESTIMATE OF XENON REACTIVITY WITH APPLICATION TO THE SER H H Baucom Atomics International Div of North American Aviation, Inc , Canoga Park, Calif May 19, 1960 47p OTS

An iterative procedure for estimating the xenon reactivity based upon computed initial conditions and build-up functions is developed Tables of the build-up are presented permitting easy evaluation of the xenon effect

106 (NAA-SR-Memo-5423) PREPOISONING OF THE S2DS. Richard Brehm Atomics International Div. of North American Aviation, Inc , Canoga Park, Calif June 20, 1960 7p. OTS.

The prepoisoning of the S2DS Reactor for Sm^{149} build-up compensation is analyzed. The methods of prepoisoning with Sm_2O_3 are proposed homogeneous loading in the core, wafers in the fuel, and wafers in the end reflectors

107 (NAA-SR-Memo-5433) WOUND-ROTOR ELECTROMAGNETIC PUMP FOR NaK. R. S. Baker and W. J. Fraser. Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif. June 22, 1960. 15p. OTS.

Design sheets were prepared for an electromagnetic wound-rotor pump developing 4 psi at 13 gpm pumping 1000°F NaK. Computations showed an efficiency of 2.8% and a weight of 71 lb. The design sheets describe the method of designing this type of pump and calculation of pump performance.

108 (NAA-SR-Memo-5716) MECHANICAL PROPERTIES OF ALUMINUM ALLOYS AT VARIOUS TEMPERATURES D E. Ellis (Atomics International Div of North American Aviation, Inc , Canoga Park, Calif.) Sept 20, 1960 10p

Studies were made to determine the mechanical properties of aluminum alloys that would be applicable to SNAP-2 radiator-condenser design The mechanical properties of 6061-T6, 2024-T3, 1100-0, and Alcoa No. 23 braze sheet were established, and the results are reported.

109 (NAA-SR-Memo-5952) AN EVALUATION OF THE COMPATIBILITY OF SOME OF THE SNAP 2 CORE MATERIALS L B Lundberg (Atomics International Div of North American Aviation, Inc , Canoga Park, Calif) Dec 9, 1960 15p

Chromium coatings on materials intended for use in the SNAP 2 core cooling system were studied for mutual compatibility under simulated reactor conditions In an attempt to improve the compatibility of beryllium with other core components the following diffusion couples were tested for 1000 hr in a 1300°F dynamic NaK system Cr plated Be-Hastelloy N, Cr plated Be-Hastelloy C, Cr plated Hastelloy N-Be, Cr plated Hastelloy C-Be, chromized Hastelloy C-Be, Ti-Be, Ti-Hastelloy N, and Ti-Hastelloy C With the exception of the chromized Hastelloy C-Be couple, diffusion was observed to take place between all of the couples tested Chrome plating separated from the beryllium during the test because of an excessively thick copper flash deposited prior to the electro-deposition of chromium

110 (NAA-SR-Memo-5961) SPACE BACKGROUND TEMPERATURE AND THERMAL RADIATION. Ernst Treuenfels (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif). Dec. 6, 1960. 11p.

The equivalent space background temperature T_B, defined by $(\Sigma Q/A\sigma\epsilon)^{1/4}$, is needed in the calculation of radiator area for the SNAP-2 program The method used previously to calculate the irradiation ΣQ for a 300-mile orbit was adapted to the calculation for the case of a 600-mile orbit Viewfactors for reflected radiation were taken to be equal to those for direct radiation.

111 (NAA-SR-Memo-5982) SHAPE OF A MINIMUM WEIGHT REFLECTOR C M Podeweltz (Atomics International Div of North American Aviation, Inc , Canoga Park, Calif) Dec 20, 1960 12p

The possibility of reducing the weight of SNAP radial reflectors while keeping their reactivity worth constant by varying their shape is analyzed in terms of reactivity weighting functions for the axial and radial directions The results are applied to the specific case of the SER (SNAP-2), a weight reduction of 12% is obtained

112 (NAA-SR-Memo-6408) SNAP 2 PRIMARY SYSTEM TEST–OBJECTIVES, SYSTEM DESCRIPTION, AND PROCEDURES G. M. Kikin (Atomics International Div of North American Aviation, Inc., Canoga Park, Calif) June 12, 1961 Contract [AT(11-1)-Gen-8] 21p

The SNAP-2 Primary System Test loop fabrication was completed with associated flight prototype components including reactor core and boiler mockups for volume and ΔP simulation, CRU-III NaK pump, compact heater, and expansion compensator A mobile loading system was designed and fabricated with the capability of cleaning the NaK prior to final loop sealing Loop descriptions, test objectives, and operating procedures are presented

113 (NAA-SR-Memo-6531) SNAP-2 SYSTEM HEAT BALANCE CODE W. Botts (Atomics International Div of North American Aviation, Inc , Canoga Park, Calif) June 21, 1961 Contract [AT(11-1)-Gen-8] 33p

A computer code was developed for use in the evaluation of the design flow rates, heat balances, and various system temperatures in the Snap-2 system The imputs to this code are the component design parameters such as efficiencies, fluid properties, power losses, and component leakage flow rates

114 (NAA-SR-Memo-6662) RESULTS OF THE S2DR REACTOR NOISE EXPERIMENT R L Randall (Atomics International Div of North American Aviation, Inc., Canoga Park, Calif.). Aug 18, 1961. Contract [AT-11-1-GEN-8] 26p

The value of (β/l^*) (the ratio of β effective to the average prompt neutron lifetime) for the S2DR was determined from measurements of the power spectral density of reactor noise signals which were obtained from an in-core BF_3 pulse chamber and a fast count rate circuit A computed "least squares" fit to the power spectral density data indicated (β/l^*) to be 1277 ± 150 sec^{-1}. This compares favorably with the calculated value of 1275 sec^{-1}. This experiment demonstrated that a pulse chamber and a fast count rate circuit make possible the precision measurement of the high frequency reactor noise components which are present in small metal reactors The addition of an FM tape recording system and modifications in the existing wave analyzer system will extend the applications and improve the precision of future reactor noise measurements

115 (NAA-SR-Memo-7527) VELOCITY DISTRIBUTIONS IN A SNAP REACTOR COOLING CHANNEL Thermo-Physics Technical Note No 2 S R. Fields (Atomics International Div. of North American Aviation, Inc , Canoga Park, Calif) June 28, 1962 Contract [AT(11-1)-Gen-8] 9p

Methods for determining the velocity distributions in a SNAP reactor coolant channel for both laminar and turbulent flow conditions are presented The results obtained by applying the methods to SNAP-2 conditions are given as maps of the ratio of local velocity to average velocity in the coolant channel The use of the velocity distributions in subsequent heat transfer analyses of the fuel rod and coolant system is discussed

116 (NAA-SR-Memo-7573) THERMAL ANALYSIS OF R-C 13, LAUNCH PHASE. P. W. Johnson (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.). July 18, 1962. Contract [AT(11-1)-Gen-8]. 50p.

Aerodynamic heating of the SNAP-2 radiator-condenser is an important design consideration. Heat creating temperatures in the 550 to 900°F range will rule out many optimum weight configurations. The effects of aerodynamic heat on the temperatures of twenty-seven specific cases of an Al-steel radiator-condenser are summarized. The maximum skin temperatures and skin-tubing differential temperatures are presented to aid in the selection of an optimum design. Future design work will be assisted by the plots of "heat sink" values as a function of temperature. In the past, various radiator-condenser designers used a minimum value of 0.2 BTU/ft^2°F; the included plot indicates the validity of this assumption. Other heat sink values ranging from 0.145 to 0.267 are presented with their maximum skin temperatures at various radiator-condenser stations.

117 (NAA-SR-Memo-7789) FOUR GROUP CROSS SECTIONS. B. W. Colston (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.). Oct. 11, 1962. Contract AT-11-1-GEN-8. 14p.

At the present, 16- and 23-energy-group calculations are impractical for 2-dimensional-diffusion or transport calculation or for 1-dimensional transport survey calculations. For this reason a set of 4-group cross sections were obtained for cores with spectral characteristics similar to SNAP 2 or SNAP 8. The results of calculations using these cross sections are compared with the results using a 23-group set. The comparison is satisfactory for the values predicted for k eff and for the power distributions. The method for obtaining the cross sections is also presented and because of the ease of obtaining new sets, it is expected that many refinements in the present set and computation of new sets for cases requiring a different spectrum will be made at the discretion of the user.

118 (NAA-SR-Memo-7945) SPIRAL BOILER EVALUATION. Jerome G. Wendt (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.). Nov. 9, 1962. Contract [AT(11-1)-Gen-8]. 19p.

The results of the boiler optimization are as follows: Approximate boiler weight (filled with NaK and Hg under operating conditions), 102 lbs; tube length, 68 ft; tube ID, 0.587 in.; surface-to-volume ratio, 25 ft^{-1}. The results of the boiler evaluation indicate that the centrifugal force produced by the spiraling effect is only $1/10$ that produced by twisted strip turbulators. Published data indicate that twisted strips do not appreciably increase pressure drop for equivalent weight flow but do increase the heat transfer coefficient. In the spiral boiler, Hg droplets are forced to only 50% of the heat transfer area, while in the twisted strip boiler, Hg droplets are forced to the entire heat transfer area. Thus a boiler with a twisted metal strip turbulator would be superior to a spiral boiler for the SNAP 2 system.

119 (NAA-SR-Memo-9043) ANALYSIS OF UPPER PORTION OF NaK OUTLET PIPE. C. C. Ramptom (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.). Oct. 8, 1963. Contract AT(11-1)-Gen-8. 106p.

The upper portion of the NaK outlet pipe of SNAP-2 was analyzed assuming the following loads: 1) thermal expansion, 2) in-plane loads from 30 g lateral acceleration, and 3) out-of-plane loads from 30 g lateral acceleration. The pipe was assumed to be elastically supported by the reactor top head and by a fixed bracket located about six inches below the top of the shield. This bracket was assumed fixed as to slope and roll. It was felt that when more experimental vibration test data are available that an intermediate lateral support may be required in the plane of the release band. Therefore, an analysis of this condition is also included. Critical loads on the reactor top head and brackets were calculated and summarized. A stress analysis of the pipe shows stresses to be low (9,300 psi) and the pipe to be adequate for the anticipated conditions.

120 (NASA-TN-D-769(p.33-44)) LIQUID-METAL CORROSION RESEARCH IN THE SNAP DEVELOPMENT PROGRAM. M. A. Perlow and J. R. Crosby (Atomics International. Div. of North American Aviation Inc., Canoga Park, Calif.).

The development of the three systems SNAP-2, SNAP-8, and SNAP-10 and liquid-metal corrosion conditions presented by each are discussed. The materials selected for core fabrication tests were stainless steels, Hastelloy, Haynes 25, Inconel X, molybdenum, and niobium. Thermal-convection loops were designed to contain the specimens in a NaK environment and to operate at temperatures from 1200 to 1500°F. The duration of testing and type and rate of attack are given for each specimen. An in-core compatibility study was made of beryllium specimens sandwiched between stainless steel 347 and Hastelloy N, both with and without interfaces of chromium and titanium. Results indicated that the chrome-plated beryllium interface withstood corrosion better than the others.

121 (TID-7599(p.263-76)) SETF REMOTE VIEWING TECHNIQUES. J. H. Burton (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.).

Windowless hot cells in the SNAP Experimental Test Facility necessitated the development of unique remote viewing equipment and techniques. The development was undertaken at Atomics International under contract to the Office of Aircraft Reactors of the Atomic Energy Commission as part of the SNAP 2 program. A description is given of the facility features and equipment that affect the remote viewing program, and the equipment and techniques developed. Mentioned are the Traverse Television System, through-roof television camera, through-roof periscope, miniature television camera, and procedures for handling and setting up the remote viewing equipment.

122 (TID-7626(Pt.I)(p.87-91)) LIQUID METAL CORROSION RESEARCH IN THE SNAP DEVELOPMENTAL PROGRAM. M. A. Perlow and J. P. Page (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.).

A discussion of the SNAP 2, 8, and 10A cooling systems is presented. Materials for use in these systems include Hastelloy C and N, Stainless 316, and Haynes alloy 25. These materials were tested in NaK at 1200 to 1500°F. Results are also discussed.

123 (TID-18880) EXPERIMENTS WITH WATER-REFLECTED, UNDERMODERATED, ZIRCONIUM HYDRIDE CRITICAL ASSEMBLIES. L. I. Moss (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.). 1963. Contract AT(11-1)-Gen-8. 38p.

A series of critical experiments was conducted with water-reflected, undermoderated zirconium hydride assemblies. The purpose of these experiments was to evaluate the consequences of water immersion of SNAP 2/10A-type reactor cores. Critical loadings were measured with several combinations of lucite rods in vacant lattice locations, beryllium inserts, internal water, neutron poison annuli at the core-reflector interface, and ammonium pentaborate in the water supply. The reactivity worth of the upper tank water as a function of height and the incremental worth of substitution of fuel rods for lucite rods was measured by the pulsed neutron method as the loading was continued past the critical point. From these measurements, an extrapolation for the excess reactivities of fully loaded, fully water-reflected assemblies was obtained. The ratio of the effective delayed neutron fraction to the effective prompt neutron generation time (ℓ^*) was measured for several unpoisoned configurations, employing both pulsed neutron and noise analysis methods. The two methods were in satisfactory agreement, giving a best value of 4.76×10^2 sec^{-1}. The corresponding value for the beryllium-reflected reactor was measured as 1.38×10^3 sec^{-1}. The much greater ℓ^* for the water-reflected assembly is attributable to reflector delayed neutrons.

124 SNAP 2. NUCLEAR SPACE POWER SYSTEM. **J. R. Wetch, H. M. Dieckamp, and D. J. Cockeram (Atomics International, Canoga Park, Calif.). Astronautics 5, No. 12, 24-5(1960) Dec.**

After a brief review of the history of the SNAP Project, the program objectives are set out and the SNAP-2 unit is described. The system consists of a 200-lb reactor, cooled by NaK, with a 1200°F outlet temperature and a hermetically sealed mercury-vapor power conversion system. The total weight is 600 lb and the output is 3 kw electrical for one year automatic. The reactor uses ZrH_4-U^{235} fuel reflected by beryllium and controlled by rotation of two semicylindrical beryllium drums. The core is a bundle of cylindrical fuel-moderator elements in steel tubes in a 9-in.-diam. core vessel. Coolant inlet temperature is 1000°F for the 50-kw thermal output. The power conversion system has a mercury-vapor two-stage axial-flow impulse turbine, an alternator, a centrifugal mercury pump, and a rotating magnet NaK pump all on one shaft, lubricated by mercury. Cycle rejection heat is radiated to space by a combined radiator-condenser which forms the outer part of the space vehicle. Shielding design and location of the unit as influenced by the space vehicle configuration are discussed, and data on dose rate versus distance are given.

125 USE OF "ON SITE" ANALOG COMPUTER TO DETERMINE DYNAMIC CHARACTERISTICS OF THE SNAP-2 EXPERIMENTAL REACTOR (SER). J. Reichman and E. B. Ash (Atomics International, Canoga Park, Calif.). Trans. Am. Nuclear Soc., 4: No. 1, 86-7(June 1961).

126 MEASUREMENT OF SNAP EXPERIMENTAL REACTOR TEMPERATURE COEFFICIENTS. J. P. Beall (Atomics International, Canoga Park, Calif.). Trans. Am. Nuclear Soc., 4: No. 1, 111-12(June 1961).

127 SNAP-2 EXPERIMENTAL REACTOR OPERATION HISTORY. M. W. Hulin (Atomics International, Canoga Park, Calif.). Trans. Am. Nuclear Soc., 4: No. 1, 145(June 1961).

128 THE SNAP 2 CONCEPT. **H. M. Dieckamp (Atomics International, Canoga Park, Calif.). Paper No. 1324-60. Presented at the ARS Space Power Systems Conference, Santa Monica, California, September 27-30, 1960. New York, American Rocket Society, 1960. 11p.**

The objectives of the SNAP 2 program are to develop, test, and qualify a 3 Kwe nuclear auxiliary power unit for space utilization prior to 1964. The over-all SNAP 2 development effort is directed toward these general objectives: minimum weight, maximum reliability, operational safety, producibility, mission environment compatibility, and minimum payload design restrictions. The results of preliminary design studies that evaluated the state of the art of reactor and power conversion technology, as well as projected space vehicle and mission requirements, have established the following specific development objectives for SNAP 2: 3 Kwe net output, one-year unattended automatic operation, system weight less than 750 lb, and cycle heat rejection area less than 110 ft^2. In order to meet these objectives, the SNAP 2 reactor employs a homogeneous fuel moderator of zirconium hydride containing 10 wt. % U^{235}. For minimum weight, the reactor is reflected by beryllium and controlled by variations of the effective reflector thickness. The SNAP 2 system employs a mercury Rankine cycle for power conversion.

129 SNAP 2 RADIATIVE-CONDENSER DESIGN. M. G. Coombs and R. A. Stone (Atomics International, Canoga Park, Calif.). Paper No. 1328-60. Presented at the ARS Space Power Systems Conference, Santa Monica, California, September 27-30, 1960. New York, American Rocket Society, 1960. 12p.

The design of a minimum weight radiative condenser for SNAP 2 requires the simultaneous consideration of many factors. These include two-phase mercury flow, a variety of heat transfer problems, meteoroid protection, and radiator geometry effects. The interactions between these problem areas are described, and the method by which a minimum weight radiative condenser for SNAP-2 was designed is presented.

130 SNAP 2 SYSTEM AND VEHICLE INTEGRATION. D. J. Cockeram and R. L. Wallerstedt (Atomics International, Canoga Park, Calif.). Paper No. 1329-60. Presented at the ARS Space Power Systems Conference, Santa Monica, California, September 27-30, 1960. New York, American Rocket Society, 1960. 9p. $1.00.

The SNAP 2 system is discussed as an item of flight hardware. The effect of vehicle limitations such as structural loadings, environmental conditions, induced torque limitations, and vehicle configurational restraints is related to final APU design. Discussions of APU influence on vehicle design are covered. Although the various APU vehicle interactions and mutual constraints are important, it is shown that timely considerations of these factors can lead to orderly development of space systems utilizing nuclear APU's.

131 **THE EXPERIMENTAL AND ANALYTICAL PROGRAMS FOR RE-ENTRY BURNUP OF SNAP REACTORS. P. D. Cohn (Atomics International Div., North American Aviation, Inc., Canoga Park, Calif.). Paper No. 1336-60. Presented at the ARS Space Power Systems Conference, Santa Monica, California, September 27-30, 1960. New York, American Rocket Society, 1960. 17p.**

The use of nuclear power in space applications is complicated by the radiological hazards that would develop if a radioactive component of a nuclear system should re-enter the earth's atmosphere, strike the earth, and contaminate a portion of terrestrial surface. Because of these hazards, analytical and experimental programs are under way to

study the possibilities of re-entry burn-up of these nuclear systems. The results of the preliminary analysis showed that complete re-entry meltdown, burn-up, and subsequent dispersion of radioactive material would take place for the SNAP 2 fuel elements above 200,000 ft. To facilitate analysis, step changes were postulated to occur in the equivalent radius of the re-entrant body to simulate the changing geometries as the system breaks up. The reactor and components were assumed to have a spherical geometry. With these assumptions the altitude for complete meltdown of the different components was calculated The model with spherical symmetry was used, except for the actual SNAP 2 fuel rods which were treated individually as tumbling cylinders. A constant re-entry angle of 1° was assumed for the calculations (to approximate a decaying orbit), and each component was assumed to be completely melted without any vaporization before the next component was exposed to heating. The atmospheric density was described by $\rho = \rho_0 e^{-\beta y}$. A similar analytical study was made for the SNAP 10 system. Results of this study predicted complete burnup for SNAP 10 fuel plates above 190,000 ft. The first phase of the experimental program consisted of heat transfer studies in which SNAP 2 fuel rods were subjected to simulated re-entry conditions in a continuous arc-jet. Excellent agreement was found between the experimental and analytical results and deviations between analysis and experiment were no greater than 10%, the analytical and measured ablation rates agreed within 10%. This agreement would tend also to verify the assumption of minimal vaporization.

132 NUCLEAR SPACE POWER–SNAP II F D Anderson, D J Cockeram, H M Dieckamp, and J R Wetch (Atomics International, Canoga Park, California) p 347-72 of "Ballistic Missile and Space Technology Vol II" New York, Academic Press, 1960

The SNAP II program objectives and status are outlined and the concepts involved are discussed at length The vehicle design considerations for application of SNAP II to satellite and space probe missions are treated Some of the safety precautions which will be used in assembling and testing the reactor are given The possible hazards associated with rocket explosion and re-entry in the atmosphere were studied and found to be not insurmountable In re-entry, the rocket may either be burnt up which results only in a low Sr^{90} level compared with that from bomb testing or be placed in orbit long enough for radioactive decay

133 STATUS OF THE SNAP 2 REACTOR R D Keen and R R Eggleston (Atomics International, Canoga Park, Calif) p 281-90 of "Space Power Systems" Nathan W Snyder, ed New York, Academic Press, 1961

The development of the Systems for Nuclear Auxiliary Power (SNAP-2) reactor is reviewed The hardware phase began with the Zero Power Critical Assembly Machine Information gained from this equipment led to the construction of the first SNAP-2 power demonstration reactor known as the SNAP Experimental Reactor (SER) Operating experience and concurrent optimization of this reactor design resulted in a "second generation" compact nuclear power reactor This reactor incorporates vehicle integration and final flight configuration considerations The design for this reactor was completed and construction is underway

134 A NUCLEAR FUEL ELEMENT FOR SPACE APPLICATION Charles C Woolsey (Atomics International, Canoga Park, Calif) p.747-67 of "Materials Science and Technology for Advanced Applications" Englewood Cliffs, N J , Prentice-Hall, Inc , 1962

The fuel element for SNAP-2 utilizes a solid-homogeneous fuel-moderator material, enriched uranium fuel in a matrix of zirconium hydride The latter has the moderating capability of cold water but maintains this capability up to temperatures as high as 1400 or 1500°F This temperature limitation results only from the increase in hydrogen dissociation pressure and the attendant hydrogen and pressure containment problems Properties of the fuel-moderator material have been studied extensively The material is quite brittle, with mechanical properties somewhat like those of a ceramic On the other hand, its thermal and electrical properties are more like those of a metal Resistance to radiation damage is excellent for the limited exposures studied Cladding material development for the fuel element has been dictated primarily by the hydrogen and pressure containment requirements

Brookhaven National Laboratory, Upton, New York

135 (BNL-801) HIGH-TEMPERATURE LIQUID-METAL TECHNOLOGY REVIEW A Bimonthly Technical Progress Review Volume 1, Number 2 O E Dwyer ed (Brookhaven National Lab , Upton, N Y) Apr 1963 Contract [AT(30-2)-Gen-16] 45p (BNL-PR-2)

Metals—technology of high-temperature liquid, review, Systems for Nuclear Auxiliary Power (SNAP-2)—coolant boiling research for, Nuclear Power Plants—development research on thermionic, Los Alamos Molten Plutonium Reactor Experiments—fuel element analysis, Heat Transfer Systems—conference on liquid metal, Bearings—coating for liquid metal, performance of, Systems for Nuclear Auxiliary Power (SNAP-8)—component development Sodium—heat transfer research on, Mercury—heat transfer research on, Potassium—heat transfer research on, Nitrogen Systems—Hg–N, flow characteristics for two-phase, Mercury Systems—Hg–N, flow characteristics for two-phase, Nuclear Power Plants—heat transfer rejection by space, research on, Alkali Metals—heat transfer research on Turbines—development of two-stage potassium, Bearings—development of liquid-metal lubricated, Niobium Alloys—properties for alkali metal containment research on Rubidium—thermophysical properties of, Los Alamos Molten Plutonium Reactor Experiments—design of LAMPRE-1

Division of Reactor Development, AEC

136 (BNL-756(p 1-18)) DEVELOPMENT PROBLEMS OF SNAP REACTOR SYSTEMS G Montgomery Anderson (Division of Reactor Development, AEC)

Materials problems in the SNAP systems imposed by the launch and space environments that are accentuated by a requirement to push to higher temperature levels and endurance than can be met by some of the more conventional materials are discussed Three SNAP systems, 10A 2, and 8, are considered One basic objective of the SNAP reactors is that the N_H (number of hydrogen atoms/cc × 10^{-22}) must be maximized to achieve a minimum system weight It is shown that fuel stability at elevated temperatures forces a compromise between allowable N_H and maximum reactor operating temperature Problems with system actuators, motors, wiring, and electronic components that must operate in a radiation field under vacuum at elevated temperatures are described

General Motors Corporation, Allison Division, Indianapolis, Indiana

137 (EDR-3113) SYSTEMS ANALYSIS OF NUCLEAR (SNAP II) LIQUID METAL CELL SPACE POWER SYSTEM. (General Motors Corp. Allison Div., Indianapolis). Dec. 5, 1962. 195p.

A systems analysis and conceptual design data are presented for a nuclear direct conversion space power system concept. This system is an electrochemical device based on concentration cell principles and employing liquid metals as reactants A detailed parametric analysis of cell performance based on current and projected technology is presented Performance and conceptual design data on other system components, such as electromagnetic pumps, regenerator, boiler-separator, condenser, cooler, and radiator, are included. Analysis of the K–Hg liquid metal cell coupled to a SNAP II reactor is also presented. Attention is focused upon a 2-kw(e) space power system, and a detailed weight breakdown is given

Sigma Corporation, Los Altos, California

138 (TID-17306) APPLICATION OF NUCLEAR POWER SUPPLIES TO SPACE SYSTEMS. (Sigma Corp., Los Altos, Calif.). June 30, 1960 For Atomics International Div of North American Aviation, Inc., Canoga Park, Calif. Contract AT-11-1-GEN-8 98p. (LA-3301)

Studies were made to ascertain what useful satellite and/or space missions may be accomplished with the SNAP 2, 8, and 10 power systems within the 1960 to 1970 time period, to delineate useful satellite and/or space missions which would most profitably employ nuclear power sources, to ascertain what restrictions are imposed on various payloads as a result of having a nuclear power system on board, and to investigate the general vehicle integration and installation requirements of the SNAP 2 and 10 power units. Space flight programs characteristics and limitations of SNAP applications of nuclear power supplies design integration and system integration are discussed

TAPCO. Division of Thompson Ramo Woolridge Incorporated, Cleveland, Ohio

139 (NAA-SR-6301) SNAP II POWER CONVERSION SYSTEM TOPICAL REPORT NO. 8, MERCURY CONDENSING RESEARCH STUDIES. R. J. Kiraly and Alfred Koestel (TAPCO. Div. of Thompson Ramo Wooldridge Inc., Cleveland). May 31, 1961. For Atomics International. Div. of North American Aviation, Inc., Canoga Park Calif.). Contract AT(11-1)-GEN-8, Subcontract N843FS-101221. 71p. (ER-4442)

Experimental results are summarized for investigations on the condenser fluid mechanics of mercury under zero-gravity, two-phase conditions. Conditions required for interfacial stability in tubes were determined as a function of tube diameters. Correlated two-phase pressure drop data are presented as functions of tube inlet Reynolds number and vapor specific volume. Flow regime stability was studied under zero-gravity and 2.55-gravity conditions and at various Reynolds numbers. The effect of non-condensable gas on flow performance in mercury forced convection condensers was evaluated.

140 (NAA-SR-6304) THE SNAP II POWER CONVERSION SYSTEM TOPICAL REPORT NO. 12. BOILER DEVELOPMENT. R. G. Gido, A. Koestel, H. C. Haller, D. D. Huber, and David L. Deibel (TAPCO. Div. of Thompson Ramo Wooldridge Inc., Cleveland). July 17, 1961. Contract AT(11-1)-Gen-8, Subcontract N843FS-101221. 146p. (ER-4521)

The SNAP II boilers which were designed are summarized. As shown by test results from the three boilers which were tested, a continuous progress in design was achieved. These designs were based on test data from both the SNAP I and SNAP II programs. As the quantity of data increased, physical models describing the heat transfer process were developed. These physical models provide the necessary correlation parameters which permit the extension of existing data to advanced design. Preliminary test sections were designed on the assumption that an all-vapor model which ignores the presence of the liquid phase during forced convection boiling could be used to describe the process quantitatively. The conventional Dittus-Boelter equation was applied with the increase in the vapor flow along the tube being ascribed to liquid evaporation. The assumption led to a design that fell short by about an order of magnitude since the exit qualities were only in the range of 10%, far less than required for complete vaporization. As a result, a revision in the concept of the mechanics of boiling was found necessary and a theoretical analysis was formulated, based on a "dry wall" or "dropwise" type boiling phenomenon. The test results of the preliminary test sections and the SNAP I boiler were plotted on the basis of dry-wall boiling parameters containing the area mean temperature difference and mass velocity. A conservative design curve was established and used to design the thirteen tube boiler. The design was found by test to be conservative, and the measured performance and the degree of conservatism were found to be within the expected spread in earlier test data. Dropwise boiling pictures the heat transfer as occurring directly from the wall to the drop through a film created by the vapor being ejected from the underside of the drop. The drop is held against the wall by its inertial force induced by a swirl device. Heat transfer experiments performed with mercury droplets provided a more detailed understanding of the mechanics of dry-wall boiling. The theory thus developed compared favorably with the test data. A boiling research program was initiated to refine the design procedures presently available. In this program the detailed heat transfer data can be derived relative to a greater number of controlled variables than are attainable in prototype boiler tests The primary efforts of the boiler development program were supplemented by other related work. These include porous bed boiler studies, mercury droplet boiling on hot plates in air, isothermal nitrogen–liquid mercury two-phase flow tests and sodium-nitrogen heat transfer tests. From these tests information was obtained on the effect of various inserts on two-phase pressure drop, the phenomena of heat transfer to drops, and the effect of primary fluid side parameters on calculation of the mercury side parameters

141 (NAA-SR-6305) THE SNAP II POWER CONVERSION SYSTEM. ORBITAL FORCE FIELD BOILING AND CONDENSING EXPERIMENTS (OFFBACE) Topical Report No 13. C T Jaenke, Alfred Koestel, and John G Reitz (TAPCO. Div. of Thompson Ramo Wooldridge Inc , Cleveland) Nov 1961. For Atomics International, Div of North American Aviation, Inc , Canoga Park, Calif Contract [AT(11-1)-Gen-8], Subcontract N843FS-101221 153p. (ER-4670)

Boiling and condensing experiments under zero gravity conditions were conducted to investigate the operation of a mercury Rankine cycle power system similar to SNAP I and SNAP II designs. A detailed analysis of the phenomena involved in condensing under various gravity conditions is included Empirical correlations based on mercury condenser pressure drop data were developed and further interfacial stability tests were made.

142 (NAA-SR-6306) THE SNAP II POWER CONVERSION SYSTEM TOPICAL REPORT NO. 14. MERCURY MATERIALS EVALUATION AND SELECTION. James F. Nejedlik (TAPCO. Div. of Thompson Ramo Wooldridge Inc., Cleveland). Apr. 10, 1961. Contract AT(11-1)-Gen-8, Subcontract N843FS-101221. 50p. (ER-4461)

SNAP II is the designation for a 3 kw nuclear auxiliary power unit to be used in a satellite vehicle. The SNAP II System consists of a reactor heat source, a boiler, a Hg Rankine engine, an alternator, and a condenser. The corrosion and subsequent mass transfer resulting from the use of Hg as the thermodynamic working fluid are important considerations in the selection of materials for the SNAP II System. Consequently, corrosion and mass transfer behavior were under study for the past three years Recent results of this study are presented and the corrosion mechanisms involved are discussed

143 (NAA-SR-6307) THE SNAP II POWER CONVERSION SYSTEM TOPICAL REPORT NO 15. CRU DESIGN AND DEVELOPMENT (TAPCO. Div of Thompson Ramo Wooldridge Inc., Cleveland) July 1961 For Atomics International. Div. of North American Aviation, Inc , Canoga Park, Calif Contract AT-11-1-GEN-8, Subcontract N 843 FS-101221. 103p. (TRW-ER-4108)

SNAP II is the designation for a 3-kw nuclear auxiliary power unit to be used in a satellite vehicle. This system consists of a reactor heat source, a mercury Rankine engine and an alternator The alternator, mercury pump, turbine, and reactor coolant pump are mounted on a common shaft supported by mercury lubricated bearings. Design details and test results concerning the combined rotating unit (CRU) development are described.

144 (NAA-SR-6309) THE SNAP II POWER CONVERSION SYSTEM. TOPICAL REPORT NO 17. MERCURY BOILING RESEARCH R. G. Gido and Alfred Koestel (TAPCO. Div of Thompson Ramo Wooldridge Inc., Cleveland) Oct. 1962. For Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif. Contract AT-11-1-GEN-8, Subcontract N843FS-101221. 184p. (TRW-ER-4833)

Activities in a boiling research program to provide data on heat transfer and pressure drop during vortex once-through forced convection boiling of Hg are reported. A test rig was built for test section configurations with swirl wire inserts; or in one case, a bare tube. Efforts were made during the testing of one swirl wire test section to obtain data on the independent effect of temperature difference, pressure level, flow rate, and quality level on heat transfer rate. The data are correlated according to forced convection vortex boiling theory. The data are meant to form part of the basis for improved design of SNAP II and similar boilers

Thompson Ramo Wooldridge, Incorporated, Cleveland, Ohio

145 (NAA-SR-6300) THE SNAP II POWER CONVERSION SYSTEM TOPICAL REPORT NO. 10, SODIUM PUMP DESIGN AND TESTING Betty A Snoke and Janis Tiltins (Thompson Ramo Wooldridge Inc , Cleveland) Aug 5, 1960 For Atomics International. Div of North American Aviation, Inc , Canoga Park, Calif Contract AT(11-1)-GEN-8, Subcontract N843-FS-101221 61p. (ER-4106)

SNAP II is the designation for a 3 kw nuclear auxiliary power unit for utilization in a satellite vehicle The SNAP II system consists of a reactor source which utilizes a mercury Rankine engine for power conversion Design details and test data for the primary fluid reactor coolant pump used to transfer heat from the reactor to the mercury boiler are described

146 (NAA-SR-6302) THE SNAP II POWER CONVERSION SYSTEM TOPICAL REPORT NO. 9, ALTERNATOR ANALYSIS, DESIGN AND DEVELOPMENT R. L Bucklin, J. W Galysh, and Hugh J Morgan (Thompson Ramo Wooldridge Inc , Cleveland). For Atomics International. Div. of North American Aviation, Inc , Canoga Park, Calif) Contract AT(11-1)-GEN-8, Subcontract N843FS-101221 56p (ER-4472)

The 3 kw nuclear auxiliary power unit designated SNAP II is intended for use in a satellite vehicle The system consists of a reactor heat source, a mercury Rankine engine, and a permanent magnet alternator The design details, test results, and development of the SNAP II alternator are presented

147 (NAA-SR-6303) SNAP II POWER CONVERSION SYSTEM TOPICAL REPORT NO. 11, ORBITAL FORCE FIELD BOILING AND CONDENSING EXPERIMENT Paul E Grevstad (Thompson Ramo Wooldridge Inc , Cleveland) Jan 15, 1960 For Atomics International Div of North American Aviation, Inc , Canoga Park, Calif Contract AT(11-1)-GEN-8, Subcontract N843FS-101221 112p (ER-4443)

The characteristics of Rankine space power plants in the zero gravity aspect of the environment of space were investigated The expected effects of Rankine space power plants are described Discussions of experimental techniques for studying these phenomena show that this information can be obtained rapidly and economically Recommendations for a program to supplement SNAP II and similar Rankine space power development efforts in this vital area are made, and consist of: the development and testing of a small system that adequately simulates a complete Rankine system, first in zero gravity and finally, in the complete orbital environment; followed by, the development and similar testing of a complete Rankine system using SNAP II hardware

148 (TID-6814) MERCURY PUMP DESIGN. THE SNAP II POWER CONVERSION SYSTEM TOPICAL REPORT NO. 5. M. A. Keresman (Thompson Ramo Wooldridge Inc., Cleveland). June 10, 1960. Contract AT(11-1)-GEN-8. 79p. (ER-4101)

Design details and test results of the jet-centrifugal mercury pump are presented.

149 (TID-6815) THE SNAP II POWER CONVERSION SYSTEM. Topical Report No. 6, Bearing Design and Development. Warren D. Waldron (Thompson Ramo Wooldridge Inc., Cleveland). June 22, 1960. 69p. (ER-4102).

A preliminary analysis conducted on various types of bearings indicated that hydrodynamic type journal and thrust bearings lubricated with a portion of the mercury from the condensate return pump would best suit the SNAP II requirements. Experimental results confirmed the bearing design approach. Stable bearing operation was obtained at speeds in excess of the 40,000 rpm design objective with simulated loads of 1 to 10 g in the radial direction, and 0 to 2 g in the axial direction. Total power consumption of the bearing system is approximately 550 watts at the design speed.

150 (TID-11307) THE SNAP II POWER CONVERSION SYSTEM TOPICAL REPORT NO. 7. MERCURY MATERIALS EVALUATION AND SELECTION James J. Owens, James F. Nejedlik, and J. William Vogt (Thompson Ramo Wooldridge Inc , Cleveland.). Oct. 26, 1960. 143p. (ER-4103)

The SNAP II system consists of a reactor heat source, a mercury Rankine engine, and an alternator. The problems involved in selecting materials for the SNAP II mercury system were studied. A discussion is given of the corrosion mechanisms involved in a system in which mercury is the working fluid. The problem resolves itself into selecting materials with the best combination of engineering properties for the application and highest resistance to mercury corrosion at the anticipated temperature.

151 SNAP II ROTATIONAL SPEED CONTROL. W E. Dauterman and E J Viton (Thompson Ramo Wooldridge, Inc., Cleveland). IRE Trans. on Nuclear Sci., NS-9 151-7(Jan. 1962).

The design and development of the rotational speed control for SNAP II has progressed to the point where experimental results have confirmed the present breadboard design approach. Frequency is controlled within ±1% and all functional control specifications of the SNAP II system were met. High temperature component testing showed that basic components are available for operation at elevated temperatures (350°C) in most areas. High temperature diodes are still not available.

152 SNAP II POWER CONVERSION STATUS. D. L Southam (Thompson Ramo Wooldridge, Inc., Cleveland). p.291-300 of "Space Power Systems" Nathan W. Snyder, ed. New York, Academic Press, 1961.

A review of the current development status of the combined rotating unit, the boiler superheater, and the load control is presented. The experimental performance characteristics of each of the components are discussed with respect to the expected influence on system operation. The critical development areas remaining for the power conversion system are presented.

SNAP—4

Atomics International, Division of North American Aviation, Incorporated, Canoga Park, California

153 (NAA-SR-Memo-7456) PHYSICAL ANALYSIS OF S4ER FUEL ELEMENTS. R. G. Matthews (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.). June 11, 1962. Contract [AT-11-1-GEN-8]. 21p.

A structural analysis of the S4ER fuel element indicates that sources of stress and instability are primarily related to assembly techniques, dimensional tolerances, temperature distribution, dynamic loads, and imposed system pressure. The derivations assume an elastic, homogeneous, isotropic material without initial stress or body forces. Hence, application of the equations without cognizance of the discontinuities produced by fabrication (e.g., residual stresses) will prove inaccurate and misleading.

Columbia University, New York, New York

154 (TID-19458) HEAT TRANSFER AND HYDRAULIC STUDIES FOR SNAP-4 FUEL ELEMENT GEOMETRIES. Topical Report No. 1. Bruce Matzner and Ralph Biderman (Columbia Univ , New York Engineering Research Labs.). Aug. 1963. Contract AT(30-3)-187 13p

Burnout, pressure drop, and heat transfer data are given for a closely spaced, wire wrapped 12-rod test section cooled by boiling water in vertical upflow at 1200 psia. The bundle consisted of (12) 0.440 in OD rods, 17 in long wrapped on a 6 in pitch with 0.022 OD hypodermic needle tubing. The rods were arranged in 3 rows of 4 rods each forming a 60° parallelogram with a minimum spacing of 0.022 in. between adjacent rods and between the outer rods and the shroud walls. The ranges of variables studied were· mass velocities between 0.85 and 4.1 × 10^6 lb/hr-ft^2, exit qualities between 8 and 21% and instrumented burnout heat fluxes as high as 0.955 × 10^6 Btu/hr-ft^2.

155 (TID-19563) HEAT TRANSFER AND HYDRAULIC STUDIES FOR SNAP-4 FUEL ELEMENT GEOMETRIES. Topical Report No. 2. Bruce Matzner (Columbia Univ., New York, Engineering Research Labs.). Sept. 1963. Contract AT(30-3)-187. 32p.

Forty-two instrumented burnout points are reported for the second 12-rod test section which had 0.440-in. diameter rods with a minimum spacing of 0.022 in. between rods. Each rod was wrapped with a 0.022-in. wire. The rods were arranged in a 3 × 4 array to form a 60° parallelogram. A contoured housing maintained the minimum spacing between the outer rods and the housing wall. The tests were performed with vertical upflow at 1200 psia The ranges of variables studied were mass velocities from 0.5 to 4 1 × 10^6 lb/hr-ft^2, exit steam qualities between 2 and 52%, and instrumented burnout heat fluxes as high as 1.28 × 10^6 Btu/hr-ft^2. The burnout results showed a strong direct mass velocity effect at exit qualities below 10%. Above 10%, an inverse mass velocity effect was seen to develop particularly at high mass velocities. All the burnouts were observed to take place on outer rods facing the unheated housing walls. Hence, these results provide an estimate of the burnout performance of only the outer rods since the interior rod surfaces have higher burnout heat flux limits in this geometry. A qualitative analysis is made for predicting the burnout location in a rod bundle. Two phase pressure drop measurements were made to show that the flow was inherently stable in the area of interest for the Snap 4 reactor. Rod surface temperatures were measured and heat transfer coefficients were calculated.

156 (TID-20046) HEAT TRANSFER AND HYDRAULIC STUDIES FOR SNAP-4 FUEL ELEMENT GEOMETRIES. Topical Report No. 3. Bruce Matzner (Columbia Univ., New York. Engineering Research Labs.). Jan. 8, 1964. Contract AT(30-3)-187. 32p.

An evaluation is being conducted of the thermal and hydraulic characteristics of a high-performance boiling water reactor, using electrically heated wire-wrapped 12-rod bundles. The test operation of Test Sections No. 3 and 4 is described. Higher burnout heat fluxes were obtained on the high power rods for the same mass velocities and exit steam qualities than for the uniformly heated test sections.

SNAP—8

(See also references 86, 89, 97, 117, 120, 122, 135, 136, 138, 223, 224, 234, 299, 319)

Aerojet-General Corporation, Azusa, California

157 (NP-13033) MERCURY CORROSION LOOP TESTING PROGRAM Report No. 0584 (Final) (Aerojet-General Corp., Azusa, Calif.). Aug. 1963 Contract NAS 3-1925. 67p

The Mercury Corrosion Loop Testing Program conducted to support materials evaluation for the SNAP-8 system program is described Niobium and 9Cr–1Mo steel alloy tubing clad with stainless steel were obtained and evaluated to determine their suitability as backup materials for Haynes 25 The test program showed that a boiling mercury loop, constructed of Haynes 25 and operated near the conditions expected in SNAP-8, could generate corrosion products that are carried over in the mercury vapor and deposited in such components as the nozzles in the turbine simulator The clad tubing concept for the materials problem in a NaK-to-mercury type boiler appeared to warrant further consideration for application in the SNAP-8 system

158 (TID-13905) SNAP-8, THE FIRST ELECTRIC PROPULSION POWER SYSTEM. P. I. Wood, D. L. Forrest, and B. M. Wilner (Aerojet-General Corp., Azusa, Calif.). [1961]. Contract [AT(10-1)-880]. 18p.

Paper No. 2050-61 for presentation at American Rocket Society, Space Flight Report to the Nation/New York Coliseum, October 9-15, 1961.

The SNAP-8 Electrical Generating System is a nuclear-turbo-electric space power plant which is ideally suited for utilization with electric propulsion. Several applications, the program objectives, the over-all system, and the design of the major components are described. The program status is delineated and future plans leading to an early flight test and equipment endurance demonstration are defined.

Aerojet-General Nucleonics Corporation, San Ramon, California

159 (NASA-TN-D-769(p.57-9)) LIQUID-METAL CORROSION RESEARCH. Malcolm F. Parkman (Aerojet-General Nucleonics, San Ramon, Calif.).

A program was planned to test niobium and stainless steel for compatibility with high-temperature liquid and gaseous rubidium. A stainless-steel capsule test was completed and negligible corrosion was observed. Design characteristics of the loops are given As part of the SNAP-8 program, loops were constructed for component testing and heat-transfer studies.

Atomics International, Division of North American Aviation, Incorporated, Canoga Park, California

160 (NAA-SR-7293) FABRICATION OF CERAMIC INTERNAL REFLECTOR FOR THE SNAP 8 EXPERIMENTAL REACTOR. K Langrod (Atomics International Div. of North American Aviation Inc., Canoga Park, Calif) July 15, 1962. Contract AT(11-1)-GEN-8. 37p.

Fabrication of internal reflector pieces for the SNAP-8 core is described. These reflectors were made of BeO, with and without the addition of Sm_2O_3 as a nuclear poison. Because of the high density and dimensional tolerance requirements, the complexity of shapes, and the comparatively modest number of parts to be produced (approximately 1000), the blanks were hot pressed and subsequently machined with diamond wheels and cores. In almost all cases, the specified density of 98% of theoretical was achieved. The low eutectic temperature in the $BeO-Sm_2O_3$ system of about 1420°C necessitated special pressing parameters, which were arrived at by experimentation. A rather coarse grit size (80) was used for the diamond wheels, which resulted in very little wear to the wheels, and an extremely low dimensional rejection rate on the blanks Because of the toxicity of BeO, all equipment was enclosed, and was held under negative pressure

161 (NAA-SR-8127) SURVEY OF METEOROID PROPERTY AND DISTRIBUTION DATA RELEVANT TO SNAP 8 REACTOR AND SHIELD DESIGN C R Harder (Atomics International Div of North American Aviation, Inc., Canoga Park, Calif). Apr 30, 1963 Contract AT (11-1)-Gen-8 40p

A survey of existing literature relative to the properties and distributions of meteoroids is presented Of major interest is prediction of the criteria which may be used to calculate the imparing effect of this meteoroidal phenomenon on the SNAP 8 space system and/or its components and other space vehicle structures

162 (NAA-SR-8468) STATISTICAL TREATMENT OF HOT CHANNEL FACTORS FOR COMPACT REACTORS. P. D Cohn and H A Evans (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.). July 15, 1963 Contract AT(11-1)-Gen-8. 39p.

The theoretical development, statistical treatment, and application of hot channel factors in compact SNAP reactors as represented by the SNAP 8 experimental core loading are presented. The channel and rod power effects of variation in the concentrations of uranium, hydrogen, and poison in the fuel rods are given. The statistical distributions of all variables are examined. A random selection of rods and channels is compared to the actual SNAP 8 configuration, with no difference noted. Confidence limits are set on hot rod and hot channel factors. Various other factors and aspects of the problem are discussed. The results of the study showed that the hot channel factors may be reduced to less than +2% over the nominal power, as opposed to a hot channel factor of about +10% as previously determined by empirical methods.

163 (NAA-SR-Memo-8675) A THREE ATOM REPRESENTATION OF FISSION PRODUCT POISONS. M W Halseth (Atomics International. Div of North American Aviation, Inc., Canoga Park, Calif). June 25, 1963 Contract [AT(11-1)-Gen-8]. 15p

Fission products were lumped together either into fast, slow, and non-burning elements or into a non-burning element and samarium-149 These elements were then used in burnup studies of two reactors The results were compared with similar results obtained by experiment or by different formulations of fission product elements

164 (NAA-SR-Memo-8817) S8DS GRIDPLATE HYDRAULICS—THERMOCOUPLE INSERTION. D L Whitlock (Atomics International Div of North American Aviation, Inc , Canoga Park, Calif). July 29, 1963. Contract AT-11-1-GEN-8 33p.

Thermocouples are required in the upper grid plate for temperature measurement of the coolant The effect on the flow rate when thermocouples were inserted into the upper grid plate of the S8DS reactor was determined The thermocouples are to be installed by remote control; therefore, the range of depth tolerance for the thermocouple was also measured. The test demonstrated that a grid plate coolant hole counterbored to 0 215 inches diameter and to a depth of 0.150 inches would permit the insertion of a 0.125 inch diameter thermocouple to a depth ranging from 0.090 to 0 110 inches without effecting the coolant flow rate in that channel

165 STATISTICAL TREATMENT OF HOT-CHANNEL FACTORS FOR COMPACT REACTORS. P. D. Cohn and H A Evans (Atomics International, Canoga Park, Calif). Trans Am. Nucl. Soc., 6· 334-5(Nov 1963).

166 SNAP 8 REACTOR AND SHIELD C. A. Johnson and C. A. Goetz (Atomics International, Canoga Park, Calif.). New York, American Inst of Aeronautics and Astronautics, 1963, Preprint 63-033, 29p (CONF-10-60)

From AIAA Electric Propulsion Conference, Colorado Springs, Colo., Mar. 1963.

SNAP 8 is a nuclear powerplant intended to produce approximately 30 kw of electric power output for use in spacecraft The system employs a nuclear reactor as the heat source for a mercury Rankine cycle power conversion system. Information is given on the design of the SNAP 8 reactor and shield. The performance requirements, design, weight, and operating characteristics of the SNAP 8 reactor are summarized and a typical shield is discussed The effects of spacecraft configuration and payload dose tolerance on shield weight for unmanned spacecraft are discussed Approximate relationships are presented to facilitate rough estimates of shield weights for preliminary design studies of unmanned spacecraft employing the SNAP 8 reactor

California Institute of Technology, Jet Propulsion Laboratory, Pasadena, California

167 (JPL-TR-32-190) TEST-BED CONFIGURATIONS FOR THE FLIGHT TESTING OF SNAP-8 POWERED ELECTRIC-PROPULSION SYSTEM. Robert J. Beale, James R. Womack, Philip J. Hirrel, and Warren C. Apel (California Inst. of Tech , Pasadena. Jet Propulsion Lab.) Nov. 24, 1961 Contract NASw-6. 36p.

A study was undertaken to determine from a conceptual approach a logical test-bed configuration to meet the following requirements (1) flight test a 30-kw(e) SNAP-8 power-generation system, (2) flight test a nominal 30-kw(e) ion motor and a nominal 30-kw(e) arc-jet motor, and (3) acquire useful spacecraft integration experience which could be directly applied to a 60- to 70-kw(e) mission spacecraft Three distinct spacecraft concepts were reviewed. (1) a 70-kw(e) interplanetary mission spacecraft (representative of an ultimate utilization for SNAP-8), (2) a 30-kw(e) earth-satellite test bed, and (3) a 30-kw(e) interplanetary test bed. The interplanetary mission spacecraft is described as a standard with which the two types of test beds can be compared For each spacecraft concept, several configurations are illustrated and described in detail The descriptions include a discussion of the propulsion system, spacecraft mode of operation, guidance, control, power conditioning, instrumentation, and telecommunications. Preliminary weight and instrumentation parameters are summarized. The technical advantages and disadvantages of the two test-bed concepts are surveyed relative to the interplanetary mission spacecraft, and the recommendation to pursue the more sophisticated interplanetary test bed is made.

Curtiss-Wright Corporation, Princeton, New Jersey

168 NUCLEAR POWER IN SPACE M C Gourdine (Curtiss-Wright Corp., Princeton, N J.) Discovery, 24: No. 7, 14-19(July 1963).

Methods to convert the energy of a nuclear reactor into electric power and electric power into thrust are discussed The development of SNAP-8 and plasma jet propulsion systems are considered. Mission parameters for planetary landings are also presented.

National Aeronautics and Space Administration, Office of Programs, Washington, D. C.

169 (NASA-TN-D-1188) GOVERNMENT-INDUSTRY CONFERENCE ON MERCURY CONDENSING, APRIL 18, 1961, PASADENA, CALIFORNIA (National Aeronautics and Space Administration, Washington, D C) Feb 1962 163p

Included are a collection of presentations on current developments by government and industrial organizations actively engaged in research and development on condensing components for Rankine cycle space power systems using mercury as the working fluid A summary of a general discussion period treating specific topics in mercury condensing is also included

170 SPACE ELECTRICAL POWER Walter C Scott and Fred Schulman (National Aeronautics and Space Administration, Washington, D C) Astronaut Aerospace Eng , 1 No 4 48-53(May 1963)

The objectives and achievements of the development program for space electrical power systems are discussed Power requirements for various space projects and products of power development research are considered Research on the radiation-resistant n-p solar cell, thin-film solar cells, and rechargeable batteries is outlined The development of Snap-8 is also discussed

171 STATUS AND TRENDS—SPACE PROPULSION A O Tischler (National Aeronautics and Space Adminis tration Washington D C) Mech Eng 85 48 55(Mar 1963)

Some of the equipment available and in development for space launch vehicles are briefly discussed Thrust increases in approximately tenfold steps and the move toward hydrogen–oxygen as a propellant for upper stages are notable trends The different propulsion requirements of the many spacecraft mission objectives are considered The potential of nuclear rockets and electric rockets is discussed The SNAP-8 electrical-generating system is described

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

172 (BNL-756(p 262-75)) LIQUID METAL RESEARCH AT NASA-LEWIS RESEARCH CENTER James P Lewis (National Aeronautics and Space Administration Lewis Research Center, Cleveland)

Liquid-metal research activities are summarized with emphasis on the heat transfer aspects of these studies A two-phase flow loop, constructed of stainless steel is being operated with sodium A sodium turbine facility, pump test facilities liquid alkali metal heat transfer facility space radiator and condenser facility and equipment for bearing and seal studies are being constructed Experiments are being planned to study the flow and heat transfer processes in a typical SNAP- adiator tube Materials support programs are discussed

173 (NASA-TN-D-1529) COLD-AIR INVESTIGATION OF PROTOTYPE SNAP-8 TURBINE William J Nusbaum and Donald E Holeski (National Aeronautics and Space Administration Lewis Research Center, Cleveland) Oct 1962. 16p

The important geometric features of a prototype SNAP-8 turbine and the results of a cold-air performance evaluation in a range of blade-to-jet-speed ratios from 0 13 to the design value of 0 3 are presented

174 SNAP-8 MATERIALS C M Scheuermann C A Barrett, W H Loudermilk, and Louis Rosenblum (Lewis Research Center, Cleveland) Astronaut Aerospace Eng , 1 40 3(Dec 1963)

The preliminary results of the reflux capsule screening program for a Snap 8 mercury containment material are presented Of all the materials tested, tantalum and niobium-1% zirconium alloy are the most corrosion re sistant They showed no measurable penetration in 2,000 hr, the limit of tests to date The martensitic and low alloy steels were next best in corrosion resistance for test times up to 5,000 hr, but exhibited measurable pene tration All other materials tested showed considerably less corrosion resistance for test times up to 5,000 hr The corrosive attack of a material by mercury is directly related to the total percentage of mercury soluble ele ments present in these materials

Pratt and Whitney Aircraft Division, United Aircraft Corporation, Hartford, Connecticut

175 (PWA-2043) DETERMINATION OF THE EMISSIVITY OF MATERIALS Progress Report, October 1 through December 31, 1961 William H Askwyth (Pratt and Whitney Aircraft Div , United Aircraft Corp , Hartford, Conn) Contract NASw-104 82p

Work in support of NASA space power systems is reported in which an aluminum phosphate-bonded coating completed 3800 hours of endurance on a SNAP-8 finned-tube radiator segment Plasma flame-sprayed coatings of titania on SNAP-8 and Sunflower I sections completed 1400 hours. A fourth rig containing a SNAP-8 section with an aluminum phosphate-bonded coating accumulated 120 hours Total emittance was measured on coatings of zirconium silicate on stainless steel strip, Rokide C on stainless steel tube, titania base powder on aluminum strip and on stainless steel strip, aluminum phosphate bonded with boron and silica on aluminum strip, aluminum phosphate bonded with silicon carbide and silica on aluminum strip, ceric oxide on stainless steel strip, acetylene black in xylol on aluminum strip, titania on aluminum strip, strontium titanate on stainless steel strip, oxidized stainless steel, and titania-alumina on stainless steel Endurance testing was conducted on the Rokide C, oxidized stainless steel, and titania-alumina on stainless steel

176 (PWA-2088) DETERMINATION OF THE EMISSIVITY OF MATERIALS Progress Report Jan uary 1–June 30 1962 W H Askwyth (Pratt and Whitney Aircraft Div , United Aircraft Corp , Hartford Conn) Contract NASw-104 22p

An aluminum phosphate-bonded mixture of nickel chrome spinel and silicon dioxide completed 7200 hours of endurance on a SNAP-8 finned-tube radiator segment Plasma flame-sprayed coatings of titania on SNAP-8 and Sunflower I sections completed 5900 hours A fourth rig containing a SNAP-8 section with an aluminum phosphate-bonded mixture of silicon carbide and silicon dioxide accumulated 4630 hours Changes in the spectral emittance rig to simplify testing provide greater accuracy and extend the range of operating conditions are described The design and construction of a new total emittance rig are described The results of an endurance test of a calcium titanate coating on a niobium tube are given

177 (PWA-2255) DETERMINATION OF THE EMISSIVITY OF MATERIALS. Progress Report, January 1 through June 30, 1963. R. J. Hayes (Pratt and Whitney Aircraft Div , United Aircraft Corp., Hartford, Conn.). 6p. (N63-22882)

Emittance measurements were made and the long-term endurance tests were concluded. The total hemispherical emittance rig has been returned to service and the quality of temperature measurement has been investigated. An analysis of slurry coating procedures is being conducted. Total hemispherical emittance measurements were made and are reported for AISI-310 stainless steel, tantalum, and coatings of crystalline boron, nickel-chrome spinel, calcium titanate, and iron titanate. All coating materials were plasma-arc sprayed onto niobium – 1 per cent zirconium tubes. Emittance values of 0.87 or above were obtained with coatings of nickel-chrome spinel, calcium titanate, and iron titanate. An endurance test conducted on a calcium – titanate coated specimen resulted in lower emittance values than anticipated but these values are not believed to be characteristic of this coating. Endurance tests were not completed for nickel-chrome spinel or iron titanate coatings. An aluminum-phosphate bonded mixture of nickel-chrome spinel and silicon dioxide on a SNAP-8 finned-tube radiator segment completed 15,000 hours of endurance testing. Flame-sprayed coatings of titania on SNAP-8 and Sunflower I sections completed 14,037 and 13,755 hours respectively. A fourth rig containing a SNAP-8 section with an aluminum-phosphate bonded mixture of silicon carbide and silicon dioxide completed 12,781 hours of testing. All tests have been terminated and the coated segments are being maintained in vacuum at ambient temperatures pending post-test analysis. The difficulties arising from the volatilization of manganese oxide in the total hemispherical emittance rig have been resolved and the rig was returned to service The quality of black-body hole configurations was re-evaluated and results substantiated previous analytical work The new evaluation included the investigation of the effects of specimen misalignment and variations in chamber geometry In conjunction with these investigations it has been found that, on the average, optical pyrometer temperature indications are 6°F higher than thermocouple indications This problem is under investigation An investigation of Alkaphos-bonded coating procedures was conducted with attention being directed toward the bonding of silicon carbide Nineteen tests were conducted using various surface preparation, drying, and curing procedures as well as various slurry compositions The best procedure found to date requires 20 hours of air drying followed by oven curing at 200°F for 2 hours, 250°F for 2 hours, 300°F for 2 hours, and 400°F for 2 hours

178 (PWA-2279) DETERMINATION OF THE EMISSIVITY OF MATERIALS Quarterly Progress Report, July 1 through September 30, 1963 R J Hayes (Pratt and Whitney Aircraft Div , United Aircraft Corp , Hartford, Conn) Contract NASw-104 45p

A screening rig was constructed to enable preliminary evaluation of coating behavior at elevated temperatures and to avoid coating volatilization in the emittance rigs Three materials have been tested to date, namely, Kennametals K-151A and K-162B and iron titanate The Kennametals were found to be stable up to 1600°F and the iron titanate up to 2000°F Emittance measurements were made for coatings of Kennametals K-151A, K-162B, nickel-chrome spinel, calcium titanate, and iron titanate Values obtained for the Kennametals ranged between 0 82 and 0 89 in the 800 to 1600°F temperature range and were in good agreement with data obtained by other investigators Emittance values obtained during the endurance testing of a nickel-chrome spinel coating were lower than anticipated, but testing a subsequent specimen coated by a modified plasma-arc spraying technique produced values of 0 90 between 800 and 1800°F Testing of a specimen coated with calcium titanate by a modified aluminum – phosphate bonding technique indicated that the resulting coating had increased stability and a higher overall emittance than previously obtained Evaluation of the endurance properties of plasma-arc sprayed calcium titanate coatings indicated that emittance values of 0 90 cannot be obtained if the specimen is initially exposed to 1000°F, although such values can be obtained by directly heating the specimen to 1400 or 1500°F Continuation of an endurance test of an iron titanate-coated specimen during the last reporting period, produced emittance values between 0 82 and 0 85 whereas values of 0 86 to 0 87 were obtained previously Post-test analysis of the radiator segments subjected to long term endurance testing in conjunction with the NASA space power systems program commenced with a residual gas analysis of the atmosphere in the chamber containing the SNAP-8 fin coated with silicon carbide and silica An attempt to apply a silicon carbide coating by aluminum phosphate bonding using the technique developed during the last reporting period resulted in unsatisfactory bonding Additional coatings have been applied by a new technique and these appear to be more satisfactory although testing at elevated temperatures has not yet been conducted

Pratt and Whitney Aircraft Division, United Aircraft Corporation, Connecticut Aircraft Nuclear Engine Laboratory, Middletown, Connecticut

179 (CNLM-5202) INVESTIGATION OF CAVITATION DAMAGE OF MECHANICAL PUMP IMPELLERS OPERATING IN LIQUID METAL SPACE POWER LOOPS. Quarterly Progress Report No. 1, June 26, 1963 to September 30, 1963 R. S. Kulp and J. V Altieri (Pratt and Whitney Aircraft Div., United Aircraft Corp. Connecticut Aircraft Nuclear Engine Lab., Middletown). Oct. 15, 1963. Contract NAS3-2541. 30p.

An investigation is being made to determine the extent of damage to an impeller operating in a known degree of cavitation in 1400°F potassium for a period of 1000 hours Preliminary tests of the impeller in water are being conducted to confirm and extend previous hydraulic and cavitation performance data of this impeller design and to calibrate the sonic techniques for establishing the desired degree of cavitation for the liquid metal test Design modifications to an existing turbopump (TP-1) to insure satisfactory high temperature liquid metal operation were completed. The impeller and pump shaft were machined in accordance with the design modifications. The impeller blade surfaces were hand polished to provide a finish of about 10 rms. The impeller was then checked dimensionally, and inspected for surface roughness. After installation in the Impeller Water Test Stand (PT-2), preliminary data runs showed the impeller to be pumping 700 gpm at a head rise of 200 feet at 6375 rpm. The minor changes required for the Water Pump Test Stand (PT-4) were designed and construction work on the stand has begun. Design changes for the Liquid Metal Test Stand (PT-6) were begun and some detail drawings were completed. Auxiliary equipment not required for this test was removed and controls rearranged for easier operation of the test.

Miscellaneous

180 POWER REQUIREMENTS FOR DIRECT-BROADCAST SATELLITES. Harold L. Davis. Nucleonics, 21: No. 1, 53-6(Jan. 1963).

Recent calculations indicate that the power needed for satellite-to-home TV receiver broadcasting is less than formerly calculated, and could easily be supplied by the SNAP-8 power supply Such a system would cost less than present systems.

SNAP—10

(See also references 83, 85, 86, 89, 97, 98, 99, 100, 120, 122, 123, 131, 136, 138, 207, 211, 223, 224, 232, 234, 319)

Atomics International, Division of North American Aviation, Incorporated, Canoga Park, California

181 (NAA-SR-7036) PROCESS DEVELOPMENT AND FABRICATION OF PbTe THERMOELECTRIC ELEMENTS. F. R. Bennett and K. Langrod (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.). Oct. 30, 1962. Contract AT(11-1)-Gen-8. 24p.

The development and fabrication of Pb-Te pellets, contacted to Fe end caps, for use as elements in thermoelectric converters for the SNAP 10A program, is described. The method adopted consists of contacting, by hot pressing in a controlled atmosphere, 24 pellets simultaneously, using 4-layer, 6-cavity graphite dies. The optimum hot pressing parameters were found to be 5000 psi at 1550°F for 30 min. Several thousand elements were produced by this relatively high-volume process, modifying the normally slow and expensive hot pressing by the use of multilayer, multicavity dies and automatic controls.

182 (NAA-SR-7288) STATISTICAL ANALYSIS OF SNAP 10A THERMOELECTRIC CONVERTER ELEMENT PROCESS DEVELOPMENT VARIABLES. S. H. Fitch and J. W. Morris (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.). Dec. 15, 1962. Contract AT-11-1-GEN-8. 41p.

Statistical analysis, primarily analysis of variance, was applied to evaluate several factors involved in the development of suitable fabrication and processing techniques for the production of lead telluride thermoelectric elements for the SNAP 10A energy conversion system. The analysis methods are described as to their application for determining the effects of various processing steps, establishing the value of individual operations, and evaluating the significance of test results. The elimination of unnecessary or detrimental processing steps was accomplished and the number of required tests was substantially reduced by application of these statistical methods to the SNAP 10A production development effort.

183 (NAA-SR-8304) PHASE I MECHANICAL AND THERMOCHEMICAL TEST SERIES. SNAP AEROSPACE SAFETY PROGRAM. S. L. Pfahler (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.). June 30, 1963. Contract AT(11-1)-Gen-8. 31p.

A description is given of the test series conducted in conjunction with the SNAP Aerospace Safety Program. The principal objective of the tests was to obtain data and information for evaluating the hazards occurring before, during, and after the flight of the SNAP 10A reactor. The results of these tests will provide a means for developing criteria to guide in the design of inherently safe SNAP systems.

185 (NAA-SR-Memo-5974) DESCRIPTION OF "SHAFT-1" CODE FOR CALCULATION OF RADIATION SHAPE FACTORS IN FINNED SYSTEMS. R. D. Elliott (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.). Dec. 15, 1960. 18p.

A high-speed digital computer program was developed for calculating the shape factors for thermal radiation from finned cylinders to the open sky. The program is to be used in performance analysis of finned radiators for the SNAP 10 Mark I thermoelectric power system. Some results are given along with a print-out of the code.

184 (NAA-SR-Memo-6515) SNAP 10A ESTIMATED ELECTRICAL CHARACTERISTICS. J. C. Cooper (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.). June 9, 1961. 8p.

The electrical power characteristics of a SNAP 10A converter are estimated for given fractions of power degradation. Graphs are included showing the power characteristics for instantaneous transients from stabilized operation at the maximum efficiency point, and after system temperature stabilization at the operating point. Open-circuit emf's of the converter are estimated for instantaneous and temperature-stabilized cases.

186 (NAA-SR-Memo-6670) PERFORMANCE TESTS OF SNAP 10A THERMOELECTRIC ELEMENTS. C. G. Bergdorf (Atomics International. Div. of North American Aviation Inc., Canoga Park, Calif.). Aug. 30, 1961. Contract [AT(11-1)-Gen-8]. 18p.

Apparatus for the performance testing of SNAP 10A thermoelectric elements was designed, constructed, and is now in operation. Elements may be tested for any desired length of time up to 1400°F and in a vacuum of 1×10^{-5} mm of Hg. The equipment used for these tests may also be utilized for measuring Seebeck coefficient and resistance as a function of temperature. Element performance is derived from the data on voltages and temperatures. The performance variables which are reported in graphic form are as follows: loaded output voltage at any desired ΔT; open circuit output voltage at any desired ΔT; power output under optimum load conditions; current produced under matched load conditions; and internal resistance of the element.

187 (NAA-SR-Memo-6921) ACCEPTOR DOPANTS FOR LEAD TELLURIDE. J. O. McCaldin (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.). Dec. 6, 1961. Contract [AT(11-1)-GEN-8]. 10p.

Alternative P-type dopants such as, Th, P, and As were studied. Ingots were grown from a melt containing one at.% dopant and their electrical properties evaluated. Also, sintered pellets of PbTe were doped by exposure at high temperature to gaseous dopants. In most cases, the doping concentrations obtained were insufficient for SNAP 10A requirements. In the case of As, however, doping of Te-rich PbTe, the desired heavy doping was obtained. These preliminary studies suggest that dopants other than Na might be suitable for SNAP 10A requirements.

188 (NAA-SR-Memo-8074) VIBRATION AND SHOCK, HIGHWAY TRANSPORT BETWEEN SANTA SUSANA MOUNTAINS AND EDWARDS AIR FORCE BASE. E. L. Gardner (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.). Jan. 25, 1963. Contract [AT(11-1)-Gen-8]. 23p.

A road test, performed on a SNAP 10A mass mockup system, indicated that shock and vibration inputs under actual conditions were not excessive. During the course of travel from the Santa Susana field laboratory to Edwards Air Force Base, and during field trials at Santa Susana, the test system was subjected to only two accelerations exceeding 2 g, and no inputs exceeded 2.4 g. It was concluded that shock and vibration to SNAP systems from highway transportation can be adequately controlled by: selecting the appropriate vehicle; providing proper packaging; specifying route and speed limits for various driving conditions; using ordinary care in loading and unloading; and including suitable shock monitoring instruments with the shipment.

189 (NAA-SR-Memo-8145) REPORT OF THE QUALIFICATION TESTING OF SNAP 10A FIXED RESISTORS. J. S. Holtwick, III (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.). Jan. 23, 1963. Contract [AT(11-1)-Gen-8]. 31p.

Upon completion of the initial visual examination and dimensional check, the resistors were weighed and the weights were recorded. The measurement of insulation resistance, performed with a megohmmeter, indicated infinity for each resistor. The dielectric strength test was performed with a high potential a-c dielectric strength tester. The test voltage was applied with no evidence of leakage or breakdown in any case. A wheatstone bridge was used to measure the d-c resistance of each resistor. All the resistors were well within their specified tolerance. The resistance-temperature characteristic test was performed in a temperature chamber at –67 to 302°F. The resistance of each was measured with a wheatstone bridge at 9 temperatures. The resistors exhibited a negative temperature coefficient, but remained within allowable tolerances. Upon completion of vibration and shock, the d-c resistance, dielectric strength, and insulation resistance, each resistor was measured. There was no evidence of damage in any case.

190 (NAA-SR-Memo-8268) STRESS ANALYSIS—EXPANSION COMPENSATOR SUPPORT STRUCTURE. J. R. Boulanger (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.). July 1, 1963. Contract AT(11-1)-Gen-8. 18p.

The structure that supports the bellows assembly in the expansion compensator was analyzed. The structure was shown analytically to take the forces to which it will be subjected. The two critical conditions considered were: during operation when the compensator has a K–Na volume of 60 in.^{3} and a temperature of 800°F. During the operating condition the stresses are sufficiently low to prevent any appreciable relaxation due to creep.

191 (NAA-SR-Memo-8824) REPORT OF THE QUALIFICATION TESTING OF SNAP 10A FUSISTORS. J. S. Holtwick, III and V. P. Nowell (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.). July 31, 1963. Contract [AT(11-1)-Gen-8]. 31p.

Qualification testing of SNAP 10A fusistors was performed. Test operations included: visual inspection, insulation resistance, dielectric strength, and d-c resistance testing prior to subjecting the fusistors to environmental testing; opening-time testing prior to, during, and following vacuum and temperature testing; and insulation resistance, dielectric strength, and d-c resistance testing following environmental applications of temperature, vacuum, and sinusoidal vibration.

192 (NAA-SR-Memo-9088) MICROPROBE STUDY OF BRAZED JOINT FOR SNAP 10A THERMOELECTRIC PUMP APPLICATION. E. L. Reed (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.). Oct. 16, 1963. Contract AT-11-1-GEN-8. 14p.

There is a program requirement to produce sound brazed joints between stainless steel and copper metal components that will remain sound after long time exposure to a high vacuum environment at a temperature of approximately 1000°F. Results are described of a microprobe study of one of the promising brazed joints after long time exposure to high vacuum conditions at a temperature of approximately 1200°F. It was desired to determine the extent of gold diffusion into the stainless steel after long time exposure under accelerated conditions. The brazing test alloy contained 81.5% gold, 15.5% copper, and 3.0% nickel. Microprobe scan photographs are shown for each of the major elements present in the test specimen and a traverse profile sketch of the braze zone is shown for the microprobe equipment set to detect gold and nickel. The results of this microprobe study indicated significant diffusion of gold into the copper metal but no diffusion of gold into the stainless steel. There were indications of minor diffusion of nickel into the copper and perhaps some concentrating of nickel atoms at the surface of the stainless steel.

193 (SC-DC-3553(p.65-78)) SNAP REACTOR TRANSIENT TESTS. L. I. Moss (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.) and T. R. Wilson (Phillips Petroleum Co., Idaho Falls, Idaho).

The SNAP reactor transient testing program (SNAPTRAN) is discussed. Typical input parameters used in the calculations are given. 14 references.

Westinghouse Electric Corporation, Lima, Ohio

194 STATIC NUCLEAR THERMOELECTRIC SYSTEM FOR SPACE. P. E. Kueser (Westinghouse Electric Corp., Lima, Ohio), P. S. Merrill, and F. G. Tauch. Preprint Paper No. 62-1436. Prepublication Copy. 10p. $1.00.

A completely static nuclear-powered thermoelectric generator is discussed The reactor designed for SNAP-10 uses U^{235}-zirconium hydride fuel moderator and is capable of operating a thermoelectric generator at a hot side temperature of 1000 to 1200°F A prototype thermoelectric generator is described which produced 250 watts of electric power at space operating temperatures Waste heat radiators for the system, having constant and tapering fin thicknesses are discussed Curves are presented of performance versus fin number and length for both tapered and constant thickness fins Weight and electric power capability of a present state-of-the-art thermoelectric generator-radiator system is presented in curve form and shows a 245-pound-weight for a 250 watt system exclusive of the reactor and shielding

Westinghouse Electric Corporation. Pittsburgh, Pennsylvania

195 (AD-282505) MODULE IMPROVEMENT PROGRAM Progress Report No 3 (Westinghouse Electric Corp Pittsburgh) Mar 15 1962 Contract NObs-84329 175p

Thorough examination of materials for use as core coatings is narrowed to inorganic oxides both in sheet form and in the form of plasma-sprayed films Exploratory investigations are made on porcelains and evaporated films of silicon monoxide Gallium–indium liquid alloy is effective in reducing the thermal drop at the alumina–thermo electric strap interface after 2600 hr/325°C plus 3300 hr/350°C in air However, at 510°C in air it loses effectiveness after a few hundred hours Under these conditions it reacts with most metals and with oxygen The development work on core coatings has resulted in materials and application methods that are giving reasonable performance in terms of dielectric strength temperature drop and life Mechanical properties of the power generation materials ZnSb, PbTe, and GeBiTe are measured A stress analysis for thermoelectric pellets and couples operating in a temperature gradient is made When this analysis is viewed from life-test results under both static and cyclic conditions, and from mechanical properties of the materials the past life performance characteristics are more clear An adequate encapsulation for GeBiTe is developed This coating is thin continuous and maintains its structure due to its excellent adherence to the GeBiTe A promising encapsulation is developed for PbTe The adherence of this composition is superior to any other, and, when used in conjunction with the encapsulation for GeBiTe gives a thin continuous coating

Westinghouse Electric Corporation, Astronuclear Laboratory, Pittsburgh, Pennsylvania

196 (AFSWC-TDR-62-119) STUDY OF BERYLLIUM BURNUP AND DISPERSION FOR RE-ENTERING NUCLEAR AUXILIARY POWER SYSTEMS A L Feild, Jr (Westinghouse Electric Corp Astronuclear Lab , Pittsburgh) Dec 1962 Contract AF29(601)-5078 152p (AD-294404)

Analytical studies were conducted to determine (1) orbital reentry burnup behavior of beryllium reflectors in SNAP reactor systems and (2) toxic hazard produced at ground level by ablated and dispersed beryllium residue from re-entering SNAP reflector Digital computer programs were formulated to calculate trajectories, aerodynamic heating, oxidations, and mass loss rates of specific beryllium shapes re-entering under proposed flight program conditions Concluding studies postulated actual reentry of a SNAP-10A reflector Toxic hazards were determined by calculation of atmospheric dispersal and fallout of beryllium particles in the toxic size range Studies concluded that varying degrees of reflector burnup will occur, depending upon reentry attitude and point of release from the reactor assembly However, no toxic hazard will exist at ground level even with complete reflector burnup at lowest possible altitude

SNAP—50

Atomic Energy Commission, Middletown, Connecticut

197 SNAP-50/SPUR REACTOR DEVELOPMENT. Frank D. Haines (Atomic Energy Commission, Middletown, Conn.). Trans. Am. Nucl. Soc., 6 88(June 1963).

The development of the refractory metal-liquid metal-cooled SNAP-50/SPUR project including, as a first reactor, the Lithium-Cooled Reactor Experiment (LCRE) is discussed. Development of SNAP-50/SPUR is intended to provide for the generation of 300 to 1000 kw(e). The overall development program will consist of a proof-of-principle, non-flight component, reactor experiment to be followed by a series of simulated flight reactor tests which will culminate in flight testing of a completed powerplant.

Princeton University, New Jersey

198 A RE-EXAMINATION OF GAS-CYCLE NUCLEAR-ELECTRIC SPACE POWERPLANTS. Jerry Grey and Peter M. Williams (Princeton Univ., N. J.). New York, American Institute of Aeronautics and Astronautics, 1963, Preprint 63036-63, 23p. (CONF-10-2)

From Electric Propulsion Conference, Colorado Springs, Colo., Mar. 1963

Five types of nuclear space power plant cycles are compared: (1) a liquid-metal cycle similar to that of the present SNAP-50, (2) a similar cycle, but using in-pile thermionic diodes instead of turbomachinery, (3) a conventional Brayton (gas) cycle, (4) a similar gas cycle, but using in-pile thermionic diodes, and (5) a new "split-radiator gas cycle." Results of these analyses are presented in parametric form, in which specific radiator weights are given at the one-megawatt level as functions of peak cycle temperature, thermionic cell efficiency, and minimum radiator temperature. The gas cycle using in-pile diodes is strongly favored by the results of the comparison, but mechanical and radiation damage considerations lead to serious contemplation of the split-radiator cycle. In this cycle, an inert gas is heated to very high temperatures (~ 3300°F) in the reactor and is cooled by a radiator, composed of thermionic diode elements, to acceptable turbine inlet temperatures. The balance of the cycle is then similar to a conventional Brayton cycle, with the turbine used only to drive the compressor. Possible cycle variations discussed include regeneration and the use of a conventional turbogenerator to supplement the thermionic powerplant output. Ideal heat transfer is assumed in all cycles. Results of these performance estimates, coupled with the qualitative considerations, indicate that the gas cycles can no longer be excluded by the liquid-metal cycle for consideration in space-nuclear power plants.

SPUR

(See also reference 197)

AiResearch Manufacturing Division, Garrett Corporation, Phoenix, Arizona

199 (ASD-TDR-63-833) BEARING ANALYSIS FOR THE SPUR TURBOGENERATOR. A. Bosco and E. Wheeler (Garrett Corp. AiResearch Mfg. Div. of Arizona). Sept. 1963. Contract AF33(657)-8954. 76p.

The results of the analysis of journal bearing configuration for the SPUR turbogenerator are presented For this analysis, a computer program was used that solves the basic hydrodynamic equations, including consideration of fluid inertia forces in both the turbulent and laminar regimes. Solutions were obtained for a number of bearing configurations, using this program, with potassium as the lubricant The computer run with laminar analysis agreed with existing solutions, thereby providing a check of the computer program. Several journal bearing mounting arrangements were considered, and a design was selected for initial testing.

200 (SY-5396-R1) SPUR POWER SYSTEM QUARTERLY PROGRESS REPORT FOR PERIOD ENDING JUNE 30, 1962 (AiResearch Mfg. Co Div. of Garrett Corp., Phoenix, Ariz) July 15, 1962. Contract AF33 (657)-8954 75p.

Research and development activities on the Space Power Unit Reactor (SPUR) are reported. The power system will consist of a reactor, a thermal-electric-energy mechanical converter, a waste heat rejector, and other auxiliary equipment. The conversion system will be of a closed-cycle dynamic type which is capable of unattended operations under specified conditions Preliminary work in the various development areas by the prime contractor and subcontractors is reported.

201 (SY-5396-R2) SPUR POWER SYSTEM. Quarterly Progress Report for Period Ending September 30, 1962. F. B. Wallace (AiResearch Mfg. Div., Garrett Corp , Phoenix, Ariz) Oct. 15, 1962 Contract AF33(657)-8954. 199p.

Activities in a program to develop a nuclear-dynamic space power system capable of supplying 300 kw of electric power with a design life of 10,000 hr are reported. The work was accomplished under phase II of the contract which provides for continued analytical and experimental studies in support of the Space Power Unit Reactor. The work is reported in sections on materials testing, bearing development, turbine development, generator development, heat transfer development, control development, and reactor loop component development.

202 (SY-5396-R3) SPUR POWER SYSTEM QUARTERLY PROGRESS REPORT FOR PERIOD ENDING DECEMBER 31, 1962. F B Wallace (AiResearch Mfg Div., Garrett Corp., Phoenix, Ariz.). Jan 15, 1963 Contract AF33(657)-8954. 192p.

Activities are reported on testing of Mo-Ti and Nb-Zr alloys, fabrication of refractory materials, testing of liquid-K bearings, design of turbine test facility, development of turbine materials, development of SPUR generator, testing of boiling-K heat transfer, development of stainless steel heat transfer components, design of heat transfer loop, and development of a reactor loop.

203 (SY-5396-R4) SPUR POWER SYSTEM Quarterly Progress Report for Period Ending March 31, 1963. F. B. Wallace and R. W. Heldenbrand (Garrett Corp. AiResearch Mfg. Div of Arizona, Phoenix). Apr. 15, 1963. Contract AF33(657)-8954. 72p.

Work in materials development was devoted to mechanical testing of Mo-Ti alloys, Nb-Zr alloys, and braze alloys in high-temperature Li and K. Other tests and developmental work on bearings, turbines, generators, heat transfer, and reactor loops are reported.

204 (SY-5396-R5) SPUR POWER SYSTEM Quarterly Progress Report for Period Ending June 30, 1963. F. B. Wallace and R. W. Heldenbrand (Garrett Corp. AiResearch Mfg. Div. of Arizona, Phoenix). July 15, 1963. Contract AF33(657)-8954. 33p.

The Phase II contract provides for continued analytical and experimental studies in support of the Space Power Unit, Reactor (SPUR) Program. Progress is reported on creep-rupture properties of molybdenum-titanium alloy, cantilever bending fatigue of niobium-zirconium alloy, mass transfer with two-phase flow, bearing tests, and properties of reactor clad and structural materials.

205 (SY-5396-R6) SPUR POWER SYSTEM. Quarterly Progress Report for Period Ending September 30, 1963. (Garrett Corp AiResearch Mfg. Div. of Arizona, Phoenix). Oct. 15, 1963. Contract AF33(657)-8954. 39p.

Progress is reported on creep-rupture and fatigue properties of molybdenum-titanium alloy, cantilever bending fatigue of niobium-zirconium alloy, mass transfer tests with two-phase flow, bearing tests, and physical and metallurgical properties of clad and structural materials

GENERAL REFERENCES

GENERAL REFERENCES

General

Aerospace Corporation, El Sequndo, California

206 (DCAS-TDR-62-121) MATERIALS PROBLEMS OF FLIGHT VEHICLE POWER. Rex A. Barney (Aerospace Corp , El Segundo, Calif) June 18, 1962 Contract AF04(695)-69 40p (AD-282348, TDR-69(2703-01)TR-1)

Information is presented on materials research in the form of a reference document It is noted that materials problems are closely related to development of energy conversion devices and are investigated concurrently in many cases However an effort was made to present information primarily concerned with materials rather than with auxiliary power technology

Army Signal Research and Development Laboratory, Fort Monmouth, New Jersey

207 (TID-6612) NUCLEAR-ENERGY POWER SOURCES. George H. Ogburn, Jr. (Army Signal Research and Development Lab., Fort Monmouth, N. J.). Feb. 1961. 15p.

Presented at the Fourteenth Annual Power Sources Conference, May 17-19, 1960, Atlantic City, New Jersey.

A discussion is given of the feasibility of the application of nuclear energy as a source of electrical power where interest concerns small light-weight sources capable of operating unattended for long periods of time in remote or inaccessible areas Radioisotope and reactor energy sources are discussed, with emphasis placed on the SNAP program developments. Characteristics are given for the SNAP-1A, -3, and -10 reactors.

Atomic Energy Commission, Washington, D. C.

208 RADIOISOTOPE POWER SOURCES J P Culwell (Atomic Energy Commission Washington, D C) IAEA Preprint No CN-14/41 18p (TID 18754)

To be published in proceedings of Conference on the Application of Large Radiation Sources in Industry, held in Salzburg, Austria, May 27 31, 1963

Radioisotope power systems are particularly suited for remote applications where long-lived compact reliable power is needed Able to perform satisfactorily under extreme environmental conditions of temperature, sunlight and electromagnetic radiations, these atomic batteries are attractive power sources for remote data collecting devices monitoring systems, satellites, and other space missions Radioisotopes used as fuels generally are either alpha or beta emitters Alpha emitters are the preferable fuels but are more expensive and less available than beta fuels and are generally reserved for space applications Beta fuels separated from reactor fission wastes are being used exclusively in land and sea applications at the present Prototype thermoelectric generators, fueled with strontium-90 and cesium 137, are now in operation in weather stations, marine navigation aids, and deep sea monitoring devices Plutonium-238 thermoelectric generators are in orbit operating as electric power sources for TRANSIT satellite Rigid safety requirements are established and extensive tests are conducted to insure that these systems can be employed without creating undue hazards

209 SPACE ISOTOPIC POWER SYSTEMS R T Carpenter (Atomic Energy Commission, Washington, D C) Astronaut Aerospace Eng , 1 No 4, 68-72(May 1963)

The current status of space isotopic power systems is reviewed Isotopic fuels technology, production, and processing, thermoelectric and thermionic power conversion technology, and aerospace nuclear safety technology are reviewed Design and performance parameters of various Snap systems and thermoelectric and thermionic generators are presented

210

REACTORS FOR PROPULSION OF MANNED AIRCRAFT AND MISSILES J E Bicknell (U S Atomic Energy Commission, Washington, D C) Texas Eng Expt Sta Misc Publ E 72-60 19-28(1960) Apr

The four programs of the Atomic Energy Commission concerned with aerospace application of nuclear energy are discussed Three are concerned with reactors for propulsion and one is concerned with the application of nuclear energy to generate auxiliary electrical power Two aeronautically oriented propulsion reactor programs are the manned nuclear-powered aircraft and the nuclear-powered ram-jet (Project PLUTO) Two space-oriented programs are the nuclear-powered rocket program (Project ROVER) and the nuclear auxiliary power program (Project SNAP) A résumé of radiological safety considerations inherently associated with aerospace applications of nuclear energy is included

211 NUCLEAR ENERGY POWER SOURCES. George H. Ogburn, Jr. (U. S. Atomic Energy Commission, Washington, D. C.). p.12-18 of "Proceedings [of] 14th Annual Power Sources Conference, 17-18-19 May 1960." Red Bank, N. J., PSC Publications Committee. [1960].

The applications of small light-weight nuclear power sources for operation without maintenance for long periods of time in remote areas are discussed. Such sources cost and weigh less than conventional chemical batteries. The SNAP program, which is developing several devices under 1 kw(e) output, is described. SNAP 10 is a reactor energy source giving 0.3 Mw(e) output from U^{235}-Zr hydride fuel and is a static, compact unit with no cooling system. Some of the possible isotopes for use in radioisotopic energy sources and their characteristics are given. SNAP III is fueled by Po^{210}, whereas SNAP 1A is fueled by Ce^{144} and is designed for use in space. Other radioisotopic units being developed are briefly described, e.g., thermionic units and units utilizing a long-lived radioisotope (Sr^{90}).

Atomics International, Division of North American Aviation, Incorporated, Canoga Park, California

212 (NAA-SR-5610) AN ENRICHED UO_2-ZrH CRITICAL ASSEMBLY. M. V. Davis, A. W. Thiele, and L. I. Moss. Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif. Nov. 1, 1960. 34p. Contract AT-11-1-GEN-8. OTS

The SNAP Critical Assembly is a pseudospherical nuclear reactor with a fixed hydrogen moderator, 93.17% U^{235} fuel, and a beryllium and graphite reflector. The core is made up of segments of cold pressed ZrH with 8% by weight UO_2 powder. The assembly is constructed in two hemispheres with horizontal faces which are brought in contact. Instrumentation and reactivity, activation, and intrinsic behavior measurements are discussed.

213 (NAA-SR-6476) BEARING MATERIALS COMPATIBILITY FOR SPACE NUCLEAR AUXILIARY POWER SYSTEMS. W. J. Kurzeka (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.). Sept. 1, 1961. Contract AT-11-1-GEN-8. 60p.

A program to evaluate materials for suitability as exposed bearings on nuclear auxiliary power systems (SNAP Program) for space vehicles is reported. Friction coefficients of material combinations in a 10^{-6} mm Hg vacuum at 1000°F for 200 hr were measured. Seven combinations found to have friction coefficients less than 0.50 are: graphite-Haynes 90; graphite-Stellite No. 3; graphite-Al_2O_3 (sprayed); Al_2O_3 (sprayed)-Cr_3C_2 (sprayed); Al_2O_3 (sprayed)-TiC; Al_2O_3 (solid)-3-F-12; and Al_2O_3 (solid)-3-N-12.

214 (NAA-SR-7085) ELECTRIC PROPULSION APPLICATIONS FOR SNAP SYSTEMS. C. J Morse (Atomics International. Div. of North American Aviation Inc., Canoga Park, Calif.). Apr. 6, 1962 Contract AT(11-1)-GEN-8. 40p.

The application of SNAP systems to electric propulsion was investigated. A review is given of the basic analysis involved in establishing optimum power levels and payload capabilities for electric spacecraft, and several typical missions are analyzed to determine the usefulness of the SNAP systems which are under development or systems which are based on the current SNAP technology. In general, it is found that SNAP power units in the range of 60 to 180 kw offer significant mission capability when used in conjunction with initial spacecraft weights of about 10,000 lb in a low-level orbit.

215 (NAA-SR-7368) SNAP SHIELD TEST EXPERIMENT REACTOR PHYSICS TESTS. R. L. Tomlinson, R. P. Johnson, and S. G. Wogulis (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.). July 15, 1962. Contract AT(11-1)-GEN-8. 30p.

The initial physics tests on the Shield Test Experiment reactor and the precriticality rod-drop test data are presented.

216 (NAA-SR-7408) APPLICATIONS OF SNAP REACTOR SYSTEMS TO COMMUNICATIONS SATELLITES. R. E. Wimmer (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.). July 30, 1962. Contract AT(11-1)-Gen-8. 124p.

Methods are presented for determining the electric power requirements of a given communications mission in terms of mission and orbit parameters. Analyses were made of possible applications of available and projected space auxiliary power units in these satellites. The satellite as a communication node is discussed. Example calculations are given.

217 (NAA-SR-7432) SNAP SHIELD TEST EXPERIMENT FISSION-PLATE POWER CALIBRATION. R. L. Tomlinson (Atomics International. Div. of North American Aviation Inc., Canoga Park, Calif.). Aug. 15, 1962. Contract AT(11-1)-Gen-8. 36p.

Three techniques were employed in measuring the fission rate of the STE (SNAP Shield Test Experiment) fission source plate, the thermal neutron absorption rate, power dissipation (calorimetric method), and the fission-neutron production technique The results obtained, when weighted according to the reciprocal of the squares of the estimated errors, yielded a fission rate of 1.97×10^{12} fissions/sec ±4% for a STE reactor power level of 50 kw Assuming that 190 Mev of usable energy is liberated per fission of U^{235}, this fission rate corresponds to a fission-plate power of 59.9 watts ±4% The calorimetric calibration technique proved to be the most satisfactory of the three techniques used The design of the STE fission source plate allowed the plate to be enclosed completely in fiberglass insulation and heated electrically as well as by nuclear means. The heating rate is sufficiently high that errors caused by ambient temperature changes are negligible. Details of the three calibration techniques employed are given The average fission-plate power per unit area was determined to be 2.05×10^{-2} watts/cm^2 ±4%, or about 14 times that of the Oak Ridge National Laboratory (ORNL) Lid Tank Facility fission plate. Although this is one-sixth that of the design value (apparently due to graphite contamination), it is satisfactory for the initial shield measurements of the SNAP Reactor Development Program. The possibility of raising the power of the fission plate at least a factor of 5 through modification of the bismuth window and graphite thermal column is being investigated. In addition, the reactor power is capable of an increase from 50 to 500 kw for short-period operation by minor changes in the external piping and replacement of the primary coolant pump. Extended operation of 500 kw would necessitate the addition of a larger heat exchanger. Ultimately, however, the STE reactor fission plate is limited to a power of about 500 watts without supplementary radiation shielding.

218 (NAA-SR-7786) KINETICS, STABILITY, AND CONTROL. A Selected Bibliography. R. L. Johnson (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.). Mar. 15, 1963 Contract AT (11-1)-Gen-8 41p.

References to 529 articles on nuclear reactor control, kinetics, and stability published before autumn 1962 are included. Emphasis is on calculations and theory since the references serve as an aid in analyzing the dynamic behavior of SNAP reactor systems.

219 (NAA-SR-Memo-5772) FARSE—A FIRST ORDER APPROXIMATION OF REACTOR SHIELDS FOR SNAP SYSTEMS, PART I—NON-SCATTERED DOSE. K. L. Rooney and M. A. Boling (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.). Oct. 11, 1960. 34p.

The FARSE code is designed to investigate the effect of complex shield geometries on over-all shield weight and payload dose profile for SNAP reactor systems. The program computes dose deposit at each target mesh from each source mesh using an attenuation model based on mean free paths traversed along a straight line trajectory. FARSE requires 51 pieces of input information per case and machine time is of the order of three to six minutes. Options in the code enable one to specify the shield and obtain the dose; or conversely, specify dose rates and tolerance across the payload and determine a shield system which will satisfy these conditions.

220 (NAA-SR-Memo-7594) RADIOGRAPHIC MEASUREMENTS OF SNAP FUEL ELEMENT END GAPS R C Barry (Atomics International Div. of North American Aviation, Inc., Canoga Park, Calif.). Dec. 7, 1962 Contract [AT(11-1)-Gen-8]. 7p

A nondestructive method was developed for measuring the spacings at the ends of fuel rods in completed SNAP fuel elements A precisely aligned radiographic technique is employed to form an undistorted image on extra fine grain radiographic film. The end gap is then measured with a 20 x measuring microscope The radiographic technique, alignment gages, and film reading methods are described for measuring gaps at the blend end and blind end of the fuel elements. The accuracy of measurements at the blend end ranges from ±0.0005 in. for spacings up to 0 010 in to ±0.002 in for spacings above 0 025 in. The accuracy at the blind end is about one-half that at the blend end

221 (NAA-SR-Memo-8440) CORE TRANSFER FUNCTION MODELS FOR SNAP SYSTEM KINETICS R L Johnson (Atomics International Div of North American Aviation, Inc., Canoga Park, Calif) Apr 29, 1963. Contract [AT(11-1)-Gen-8] 34p

A distributed parameter transfer function is developed for SNAP type reactor cores The coolant may be either boiling, non-boiling, or both In the boiling case the Bankoff model is used to find the spatial distribution of voids The transfer functions obtained are not simple polynomials However, they are readily analyzed for stability using the 7090 program TRAFIC, which uses a Nyquist diagram approach Some general conclusions resulting from these calculations are included

222 (NAA-SR-Memo-9101) STREP (SNAP TEMPERATURE REDUCTION PLOTTING). Katharine W. Medeiros (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.). Oct. 1963. Contract [AT(11-1)-Gen-8]. 67p.

STREP is a general-purpose program for linear plotting of parameters, in optional groupings, against a common abscissa.

223 (TID-6312) THE PRACTICAL APPLICATION OF SPACE NUCLEAR POWER IN THE 1960'S. J. R. Wetch, H. M. Dieckamp, and G. M. Anderson (Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.). Feb. 1961. 50p. Contract AT-11-1-GEN-8.

Nuclear reactor space electric power units under development in the U. S. include the SNAP-2, SNAP-8, and SNAP-10. The electric power output of these Systems for Nuclear Auxiliary Power (SNAP) extends over three decades of power, from 300 watts to 60 kilowatts. The major operational, installation, and handling characteristics of these nuclear power units are described. In particular, some limitations and restrictions with regard to payload, shielding, and radiation environment are described with respect to the power plants, their mode of installation, and system weight. The ground handling and safety, as well as the over-all safety, aspects of space reactor utilization are also described. The SNAP-10 power unit is a demonstration system that utilizes thermoelectric power conversion. The SNAP-2 power system utilizes a similar compact nuclear reactor, which is cooled with liquid sodium-potassium alloy, and coupled to a small mercury vapor turbine generator power conversion system. The SNAP-8 system is a direct outgrowth of the SNAP-2 power plant development. It will deliver 30,000 watts with one mercury vapor turbine generator system and weighs about 1400 lb.

224 NUCLEAR AUXILIARY POWER—WATTS TO MEGAWATTS WITH SNAP. Ralph Balent (Atomics International, Canoga Park, Calif). IRE Trans on Nuclear Sci , NS-9 27-33(Jan 1962).

Full utilization of the capability of advanced booster systems can only be realized if adequate auxiliary power units are integrated into the payload vehicle. Nuclear power units offer unique advantages for space application, including compactness, light-weight, long reliable life, elimination of need for secondary batteries and sun orientation requirements, growth potential from hundreds of watts to megawatt range, and development of qualified units on a time scale that is consistent with present expected payload growth capability. Studies showed that solar cells and nuclear isotope auxiliary power systems have application in missions with power requirements up to a few hundred watts. Solar dynamic and nuclear reactor systems are competitive for the sub-kilowatt to few kilowatt level. However, beyond this range compact reactor systems are the only feasible way of obtaining the power needs for advanced missions. Compact reactors and power conversion equipment for space application are under development under AEC, NASA, and DOD sponsorship, where today three SNAP (Systems for Nuclear Auxiliary Power) reactor projects are now programmed for early orbital flight testing. These are the 500 watt SNAP 10A, the 3Kw SNAP 2, and 30/60 Kw SNAP 8 systems. Advanced space systems capable of producing hundreds of kilowatts with extension into the megawatt range with less than 5 lbs/kw specific weight are now under study.

225 PRECISION NONDESTRUCTIVE TESTING OF THERMOELECTRIC MATERIALS S H Fitch and J W Morris (Atomics International, Canoga Park Calif) Nondestructive Testing, 21 306-10(Sept –Oct 1963)

The direct conversion of heat to electrical energy and the application of this (thermoelectric phenomenon to Systems for Nuclear Auxiliary Power (SNAP) for space vehicles is discussed The development of a complete quality control system for the evaluation of thermoelectric materials, as-received, in-process, and after assembly, is outlined. The contributions of nondestructive testing and statistical quality control in enhancing the assurance of acceptable quality and reliability of the end product are demonstrated by actual test records and control charts.

226 THE SHIELDING PROGRAM FOR SNAP REACTOR SYSTEMS. Walter M. Cegelski (Atomics International, Canoga Park, Calif.). Trans. Am. Nuclear Soc., 5: No. 1, 215-16(June 1962).

227 THE APPLICATION OF MONTE CARLO CALCULATIONS TO SNAP REACTOR SHIELDS. Kevin L. Rooney and William J. Roberts (Atomics International, Canoga Park, Calif.). Trans. Am. Nuclear Soc., 5: No. 1, 216-17(June 1962).

228 EXPERIMENTS AND ANALYSIS OF WATER-REFLECTED, UNDERMODERATED ZIRCONIUM-HYDRIDE CRITICAL ASSEMBLIES. PART I. EXPERIMENTS. L. I. Moss (Atomics International, Canoga Park, Calif.). Trans. Am. Nucl. Soc., 6: 49-50(June 1963).

229 EXPERIMENTS AND ANALYSIS OF WATER-REFLECTED, UNDERMODERATED ZIRCONIUM-HYDRIDE CRITICAL ASSEMBLIES. PART II. ANALYSIS. B. W. Colston (Atomics International, Canoga Park, Calif.). Trans. Am. Nucl. Soc., 6: 50-1(June 1963).

230 SHIELD DESIGN FOR SNAP REACTORS. V. Keshishian (Atomics International, Canoga Park, Calif.). Paper No. 1334-60. Presented at the ARS Space Power Systems Conference, Santa Monica, California, September 27-30, 1960. New York, American Rocket Society, 1960. 14p.

Studies of the SNAP reactors showed that, depending on vehicle, component, and shielding arrangement, shield weights can vary from zero to a few thousand pounds. Since the SNAP reactors are very small in size, it was found to be advantageous to place all of the shield around the reactor to achieve a minimum system weight. To show the effect of vehicle layout on shield weight, a variety of cases was considered. Lithium hydride was assumed to be the shielding material in each case. Figures illustrating the various configurations are included.

231 EVALUATION OF SNAP SAFETY FOR SPACE REACTOR APPLICATION. F. D. Anderson and J. G. Lundholm, Jr. (Atomics International, Canoga Park, Calif.). Paper No. 1335-60. Presented at the ARS Space Power Systems Conference, Santa Monica, California, September 27-30, 1960. New York, American Rocket Society, 1960. 15p. $1.00.

The major operational periods investigated for the safety of SNAP systems for space reactor applications are (1) shipment and integration period, (2) launch pad period, (3) launch period, and (4) re-entry period. All areas were investigated for possible safety problems. Results of these studies indicate that periods except re-entry can use presently known safety procedures to ensure safety of the SNAP systems. In addition to the routine safety procedures, decontamination and monitoring equipment as well as specific launch pad procedures will be necessary for emergency situations. Only the re-entry period contains areas which may present safety problems because of the uncertainty of re-entry burn-up and high altitude dispersal of the SNAP fuel elements. Until re-entry burn-up can be assured, orbital start-up and high altitude orbits ($\approx$ 700 miles) can be used to assure safe re-entry. When re-entry burn-up and high-altitude dispersal is proved, the re-entry of SNAP units will not add significant contamination to the biosphere.

232 SNAP THERMOELECTRIC SYSTEMS. A. W Thiele and M. G. Coombs (Atomics International, Canoga Park, Calif.). Paper No. 1330-60 Presented at the ARS Space Power Systems Conference Santa Monica, California, September 27-30, 1960. New York, American Rocket Society, 1960. 8p.

In the range of moderate electrical power requirements (~1 kw) thermoelectric power conversion techniques offer many advantages in the design of nuclear auxiliary power units for space application. The current temperature capability of the lead telluride class of thermoelectric materials, in the vicinity of 1100°F, can easily be met with the demonstrated performance of the SNAP reactor systems. Minimum system weights are obtained at Carnot cycle efficiencies of the order of 25%, yielding a total system efficiency of about 3%. SNAP 10, a 300-watt system is now under development This system will have the capability to withstand missile launch environment and accomplish complete orbital start-up.

233 THE APPLICATION OF SNAP UNITS IN CURRENT SPACE VEHICLES. J. R. Wetch and J. G. Lundholm, Jr. (Atomics International, Canoga Park, Calif.). Paper No. 1337-60. Presented at the ARS Space Power Systems Conference, Santa Monica, California, September 27-30, 1960. New York, American Rocket Society, 1960. 8p. $1.00.

The expected uses of SNAP systems with space vehicles which will be available during this decade are discussed. It is shown that existing booster vehicles have payload capabilities such that significant useful payloads can be carried in addition to a SNAP system. The advantages of employing SNAP systems in conjunction with electric propulsion devices and wide band communications systems are discussed.

234 NUCLEAR REACTOR SPACE POWER SYSTEMS. J. R. Wetch and M. G. Coombs (Atomics International, Canoga Park, Calif.). Preprint Paper No. CP 62-1203. New York, American Institute of Electrical Engineers, 1962. 13p. $1.00.

The status of the space reactor program is reviewed. The SNAP 10A, a 500-watt thermoelectric system; the SNAP 2, a 3-kw mercury turboelectric system; and the SNAP 8, a 30-kw scale-up of the SNAP 2 system are described. Factors that influence the design of a nuclear space power system are presented, and the prospects for future higher power nuclear systems are discussed.

235 RADIATION EFFECTS ON ELECTRICAL INSULATION FOR COMPACT REACTORS IN SPACE. J. W. Ramsey and M. Warren (Atomics International, Canoga Park, Calif.). New York, Institute of Electrical and Electronic Engineers, 1963, Preprint Paper CP63-1182, 14p. (CONF-1-24)

From Institute of Electrical and Electronics Engineers 1963 Summer Meeting, Toronto, June 1963.

Radiation experiments were conducted on high-temperature electrical encapsulants and electrical connectors in order to evaluate their performance for use in the unique combined environment of reactor, radiation, high temperature, and vacuum to be found in the SNAP reactor operational environment during space flight. In general, the insulating cement and the connector insulations showed a decreasing insulation resistance with time when tested at 800°F and 10^{-5} Torr vacuum both in the reactor and out of the reactor No gross effect of radiation appeared on the resistance of three insulation materials when tested at 800°F in a 10^{-5} Torr vacuum with radiation flux of 6.5 × 10^{12} nv neutrons (>0.1 Mev) and 2 7 × 10^{7} R/hr gamma

Avco Corporation, Research and Advanced Development Division, Wilmington, Massachusetts

236 (RAD-TR-61-28) INVESTIGATION OF RE-ENTRY DESTRUCTION OF NUCLEAR AUXILIARY POWERPLANT. (Avco Corp. Research and Advanced Development Div., Wilmington, Mass.). Oct. 1961. Contract AF33(616)-7530. 366p. (AFSWC-TR-61-69)

Work was undertaken to determine how the re-entry of a nuclear reactor from orbit can be made inherently harmless by the re-entry environment alone and without the use of fallible components Accordingly, the problems involved in the re-entry destruction of a nuclear reactor—fuel-element exposure, meltdown of the fuel elements, dispersal of the molten residue, and combustion of the molten residue—were investigated by theoretical and experimental techniques. Results of this study indicate that without modification, flight models of the August 1960 developmental reactor-vehicle systems considered will not be reduced to a harmless residue by the re-entry environment However, the parametric and design studies are relatively general, and they may be useful to designers in developing this and other reactor-vehicle systems for safe re-entry. This study recommends one method by which the reactor safety may be improved by design changes. The separate aspects of the re-entry sequence of destruction of the SNAP system and flight test recommendations are discussed. Detailed recommendations for a flight test program to prove the safety of a reactor designed for re-entry destruction are presented.

Division of Reactor Development, AEC

237 (CONF-311-8) AEC AEROSPACE SAFETY PROGRAMS AND PHILOSOPHY. Frank K. Pittman (Division of Reactor Development, AEC). Oct. 1, 1963. 12p.

From American Nuclear Society Aerospace Nuclear Safety National Topical Meeting, Albuquerque, N. Mex., Oct. 1963.

Work in aerospace safety analysis, research, development, and testing is discussed. Studies for the SNAP program are outlined. The engineering and test program for aerospace safety is described.

Division of Technical Information Extension, Atomic Energy Commission, Oak Ridge, Tennessee

238 (TID-3561(Rev. 3)) DIRECT ENERGY CONVERSION DEVICES AND SYSTEMS FOR NUCLEAR AUXILIARY POWER (SNAP). A Literature Search. Sidney F. Lanier and Henry D. Raleigh (Division of Technical Information Extension, AEC). Jan. 1963. 63p.

A total of 553 references are listed on the SNAP program and related topics. The references were taken from Nuclear Science Abstracts to Dec. 31, 1962. The contents are arranged in sections on radioisotope-fueled units, reactor-fueled units, direct energy conversion, and general topics on nuclear auxiliary power.

Electro-Optical Systems, Incorporated, Pasadena, California

239 ELECTRIC PROPULSION AND POWER. John M. Teem (Electro-Optical Systems, Inc., Pasadena, Calif.), and George C. Szego. Astronaut. Aerospace Eng., 1: 98-103(Nov. 1963).

Progress in electric propulsion systems, thrustor research and development, applications, and mission analysis are discussed. Some types of electric power systems and their applications are presented. These include solar cells and collectors, the SNAP program, radioisotope systems, thermoelectric and thermionic technology, MHD power, batteries and fuel cells, and power conditioning.

General Dynamics / Astronautics, Space Science Laboratory, San Diego, California

240 (AFSWC-TDR-62-15) REENTRY OF SNAP REACTOR BERYLLIUM REFLECTORS. EFFECT OF FAST NEUTRON PRODUCED INTERSTITIAL HELIUM NUCLEI. A. Vampola (General Dynamics/Astronautics. Space Science Lab., San Diego, Calif.). Mar. 1962. Contract AF29(601)-4893. 6p. (AD-273169)

The effects of interstitial He nuclei produced in the Be by fast neutrons are discussed as a possible mechanism of Be degradation and hence a contributing mechanism of dispersal. The sizable cross sections for production of He^4 under fast neutron bombardment of Be indicated that interstitial He nuclei would be produced within the Be. It was shown that the total gas volume involved was too small to produce significant changes in density, yield strength or brittleness of the Be. The irradiated reflector metal, therefore, should react in the same manner as unirradiated Be upon reentry.

General Electric Company, Advanced Technology Services, Cincinnati, Ohio

241 (GEMP-245) 710 REACTOR PROGRAM TEST PLANS AND FACILITY REQUIREMENTS. (General Electric Co. Advanced Technology Services, Cincinnati). Oct. 15, 1963. Contract AT(40-1)-2847. 42p.

Conceptual studies were completed that define the philosophy, plans, radiological hazards, and facility requirements for development testing of the 710 reactor system. Conceptual test sites and facility arrangement options were considered. Detailed test plans, estimated facility costs, and construction schedules are included.

General Electric Company, Hanford Atomic Products Operation, Richland, Washington

242 (HW-66666(Rev 2)) REVIEW OF POWER AND HEAT REACTOR DESIGNS Domestic and Foreign E R Appleby, comp (General Electric Co Hanford Atomic Products Operation, Richland Wash) Oct 1963 Contract AT(45-1)-1350 279p

Unclassified information from domestic and foreign literature from January 1952 through September 1963 is compiled Design characteristics and current information on the status of the individual designs are given along with references for the associated literature SNAP systems proposed reactors, and chemonuclear and test reactors with characteristics similar to power reactors are included The designs are indexed by name, location, type, and some special characteristics

Geoscience Limited, Solana Beach, California

243 (TID-18028) HIGH ACCELERATION FIELD HEAT TRANSFER FOR AUXILIARY SPACE NUCLEAR POWER SYSTEMS Annual Technical Report, September 1, 1961 through August 31, 1962. H F Poppendiek, N D. Greene, F R MacDonald, H. R. Wright, C. M Sabin, and A S Thompson (Geoscience Ltd., Solana Beach, Calif.) Contract AT(04-3)-409. 157p (GLR-10)

The auxiliary power research program by Geoscience which encompasses both fundamental liquid metal boiling and condensation heat transfer analyses and experiments in linear and high gravity flow through ducts is discussed This research will permit the development of design correlations and criteria necessary for the prediction of nuclear reactor and heat exchanger performance in space power systems A review and summary of post liquid metal heat and momentum transfer research, two-phase flow analyses, two-phase flow measurements, a comparison of analytical and experimental two-phase flow results, a boiling heat transfer system design, Mollier diagrams and physical properties for mercury and potassium, and a study of the influence of sudden coolant density changes on core heat transfer rates are presented

Institute for Defense Analyses, Washington, D. C.

244 SPACE POWER SYSTEMS George C Szego (Inst for Defense Analyses, Washington, D C) Proc Am Power Conf , 25 45-82(1963)

A review is presented of power systems for the navigation of space The power system is divided into three parts (energy source, conversion system, and waste-heat rejection system), and each is discussed in some detail The problem of meteorite damage is considered Specific power sources are discussed radioisotope, nuclear, solar energy conversion, fuel cells chemical rotating systems, and static thermal energy conversion Comparisons are made of the performance of competitive systems

Kaiser Aircraft and Electronics, Oakland, California

245 POWER SYSTEMS. Nathan W. Snyder (Kaiser Aircraft and Electronics, Oakland, Calif.). Astronautics, 7. No. 11, 110-14(Nov. 1962).

Low power output of other devices at this time dictates the use of nuclear-reactor systems for manned space explorations Work up to the present is briefly reviewed, and progress and utilization of other power supplies are discussed Pros and cons of solar cells, fuel cells, and thermoelectric and thermionic devices are included as well as consideration of energy storage, solar energy collector technology, and heat transfer and rejection for space power

Kernforschungszentrum, Karlsruhe, Germany

246 RADIONUCLIDE-BATTERIES FOR SPACE TRAVEL Hans-Keiko Stamm (Kernforschungszentrum Karlsruhe, Ger) Weltraumfahrt, No 4, 101-6(1963) (In German)

The use of radioisotope-fueled thermoelectric or thermionic cells for electric energy production in space vehicles is discussed Energy change and construction of the radionuclide batteries are described The use of Sr^{90}, a mixture of fission products, Po^{210}, Pu^{238}, Cm^{242}, or Cm^{244} as the heat source is discussed Generators being built or planned are described briefly Safety studies are described

Lockheed Missiles and Space Company, Sunnyvale, California

247 (AD-423714) AUXILIARY POWER SYSTEMS FOR SPACECRAFT AN ANNOTATED BIBLIOGRAPHY Peter R Stromer, comp (Lockheed Missiles & Space Co., Sunnyvale, Calif) May 1963 Contract AF04(695)-136. 60p (SB-63-46)

References (135) from the 1962—1963 literature reporting research and development in auxiliary power systems for spacecraft are included Solar and nuclear auxiliary power sources are emphasized with only a representative sampling of concepts such as magnetohydrodynamics, biochemical and hydrox fuel cells, batteries etc Subject and corporate source indexes are provided

Martin-Marietta Corporation, Aerospace Division, Baltimore, Maryland

248 A/CONF.15/P/833
Martin Co , Baltimore
POWER FROM RADIOISOTOPES. Kenneth P. Johnson 14p. $0.50(OTS).

Prepared for the Second U. N International Conference on the Peaceful Uses of Atomic Energy, 1958

The use of radioisotopes as a source of power is discussed. Two power ranges, ten and 500 watts, are explored. The selection of fuel is determined by power density in realizable form, cost, availability, shielding, and biological hazards considerations. A list of feasible radioisotopes is presented based on the above considerations. These radioisotope fuels are divided into the two categories of reactor produced and fission products. Particular emphasis is placed on practical engineering problems to be considered in fuel selection such as minimization of biological hazards and radiological shielding requirements. Fuel element design and fabrication is discussed to illustrate realizable fuel forms and manufacturing techniques which might be employed. Radioisotope availability at the present time is a major consideration in view of the limited number of radioisotope separation and handling facilities. Future possibilities in the area of cost and availability are explored in the light of rising demand for radioisotope fuels. Power conversion systems are discussed with respect to the two levels of power being explored.

249 (CONF-17-7) POWER APPLICATIONS OF RADIONUCLIDES. Justin L. Bloom (Martin-Marietta Corp. Aerospace Div., Baltimore). [1963]. Contract [AT(30-1)-2345]. 26p.

From Oak Ridge Radioisotope Conference on Applications to Physical Science and Engineering, Gatlinburg, Tenn., April 1963.

The development and uses of SNAP power supplies which derive their energy from the decay of radioactive isotopes are discussed.

250 MND-1666
Martin Co. Nuclear Div., Baltimore.
A PRELIMINARY EVALUATION OF NUCLEAR THERMOELECTRIC AND THERMIONIC (SECONDARY) POWER PLANTS FOR SPACE USE. Robert J. Harvey, Fred N. Huffman, and C. Eicheldinger. [1958]. 151p.

The unclassified aspects of a preliminary investigation and conceptual design of a thermoelectric and a thermionic space power supply, utilizing reactor heat sources, are summarized. A set of ideal specifications was established as a guide for the investigation of both systems, and various reactor types and concepts were considered. The general design of a space radiator is discussed. The basic theory of both types of generators is reviewed.

251 (MND-2584-4) RADIOISOTOPE SEMICONDUCTOR AND THERMOELEMENT RESEARCH AND DEVELOPMENT. Final Technical Report, February 13, 1961—July 17, 1962. N. G. Asbed (Martin-Marietta Corp. Aerospace Div., Baltimore). Contract AT(30-1)-2698. 74p.

A description is given of work in support of the concept that a radioisotope can be made an integral part of the thermoelectric arm of a generator and that the decay energy of the emitted particles can be converted to electricity by direct conversion. In particular, n-type strontium and cerium titanates were prepared to house strontium-90 and cerium-144, respectively. The blend consisting of $SrTiO_3$ (+20-wt % Fe) +20-wt % $CeTiO_3$ has an average figure of merit of 1.9×10^{-4} °C^{-1} between 200 and 1100°C; the corresponding thermoelectric conversion efficiency is ~4%. Strontium titanate was prepared by reacting strontium carbonate and titanium dioxide in air. The addition of 20-wt % pyrophoric iron and the subsequent reduction in dry hydrogen at 1475°C rendered the titanate into an n-type semiconductor with a thermoelectric figure of merit of 1.1×10^{-4} per degree centigrade at 600°C. This material withstands temperatures to 1200°C in the absence of oxygen, without a deterioration of its thermoelectric properties. The material is mechanically strong and hard. Cerium titanate was prepared for the first time by a process similar to the one used to make semiconducting strontium titanate, and was shown to have the formula $CeTiO_3$. A thermoelectric arm of iron-doped strontium titanate was prepared, with 20 curies of strontium-90 concentrated as an ingredient of the thermoelectric material at one end. This device had an open-circuit emf of 1.20 millivolt, and delivered 0.48 microwatt to a matched load. A program for the IBM 7090 computer was modified to permit optimization of a thermoelectric arm, of varying composition, which contains an internal heat source.

252 (MND-3143-1) INVESTIGATION OF GAS PRESSURE BUILDUP IN THERMOELECTRIC SNAP GENERATORS. W. A. McDonald and J. McGrew (Martin-Marietta Corp. Aerospace Div., Baltimore). Jan. 1964. Contract AT(30-1)-3143. 43p.

The program for investigating gas pressure buildup in thermoelectric generators was initiated in February 1963 and continued through December 1963. The program objectives were to determine the source(s) of internal gas pressure increase in SNAP thermoelectric generators, establish methods of alleviating or eliminating the condition, and conduct a proof-of-principle test on an electrically heated 60-watt thermoelectric SNAP generator to determine the effectiveness of the procedures developed to control or eliminate the condition. The gas pressure increase in the generators that were initially filled with dry inert gas results from decomposition of the phenol-formaldehyde resin that is used as a binder in the Min-K 1301 thermal insulation and desorption of atmospheric gases and water vapor that adsorb on the surface of the insulation. The degree of gas release in both cases was determined to be temperature and pressure dependent. The recommended procedure to control gas pressure buildup for all future generators is: (1) precondition the Min-K by burning off the phenolic resin binder; (2) vacuum outgas the insulation at a temperature above its maximum operating temperature; and (3) install a gas getter (zirconium) to absorb any gases that may be released during subsequent generator operation. The complete recommended procedure to control this pressure buildup could not be employed in the 60-watt thermoelectric SNAP generator test since the generator had been previously constructed and assembled using Min-K that had not been preconditioned by outgassing. Therefore, a modified outgassing procedure was established for the generator when the test was initiated. The procedure, in essence, specified that the generator be maintained on continuous evacuation while the thermoelement hot junction temperature was slowly increased to ~525°F, and that the generator be subjected to frequent rapid evacuations and gas changes as the temperature was increased to 960°F. (Lead telluride thermoelements begin to sublime in a vacuum at elevated temperatures in the 950 to 1000°F range.) An amount of 2,143 grams of zirconium sponge were inserted in the hottest region of the generator to react with getterable gases that remained after the outgassing and evacuation procedure. The 60-watt electrically heated SNAP generator was then maintained on a stability test for two months. The generator internal gas fill pressure remained essentially constant throughout the period, demonstrating that the recommended control procedure will alleviate the internal gas pressure buildup condition.

253 MND-Lib-1631
Martin Co., Baltimore.
THERMOELECTRIC POWER SOURCES: AN ANNOTATED LITERATURE SEARCH. PART I. George E. Halpern and Elizabeth G. Sanford. Dec. 5, 1958. 24p.

A literature search for information concerning thermoelectric power sources was conducted. The search covered the literature from 1954 to 1958 except for Nuclear Science Abstracts coverage, which was from 1948 to 1958. Sources consulted in addition to NSA were Technical Abstract Bulletin, Engineering Index, and Industrial Arts Index.

254 (MND-P-2048) HAZARDS SUMMARY REPORT FOR A TWO WATT STRONTIUM-90 FUELED THERMOELECTRIC GENERATOR. (Martin Co. Nuclear Div., Baltimore). June 1959. Decl. Sept. 19, 1960. 34p.

A hazards survey was made of the Auxiliary Power Unit (APU) which utilizes the decay products from 8,300 c of Sr^{90} and its daughter, Y^{90}, to generate thermal energy. A diagram and description of the Sr^{90}-fueled APU are given. The location, temperature effects, emergency provisions, and structural requirements involved in the integration of the generator into the Discoverer or Sentry vehicles are discussed. The properties of Sr^{90} are given. Shielding requirements were imposed primarily by weight limitations rather than by a predetermined design dose rate. The radioisotope must be contained under any conceivable condition, operational or accidental, when it is in the biosphere. The most stringent conditions in terms of internal and external mechanical, thermal, and chemical forces serve as design criteria. The hazards design criteria were determined by extreme conditions including handling accidents, missile vehicle failures, and re-entry through the atmosphere and subsequent earth impact.

255 (MND-P-2049) HAZARDS SUMMARY REPORT FOR A TWO WATT PROMETHIUM-147 FUELED THERMOELECTRIC GENERATOR. (Martin Co. Nuclear Div., Baltimore). June 1959. Decl. Sept. 19, 1960. 35p.

Discussions are included of the APU design, vehicle integration, Pm^{147} properties, shielding requirements, hazards design criteria, statistical analysis for impact, and radiation protection. The use of Pm^{147} makes possible the fabrication of an auxiliary power unit which has applications for low power space missions of <10 watts (electrical).

256 (MND-P-2316) LOADING, SHIPPING AND TESTING PROCEDURES FOR TASK 2 ISOTOPIC POWERED THERMOELECTRIC GENERATOR. Preliminary Technical Manual. M. J. Reilly. Martin Co. Nuclear Div., Baltimore. Mar. 24, 1960. 44p. Contract AT(30-3)-217. OTS.

A preliminary report on the operations and procedures for handling a 125-w thermoelectric generator and its isotopic heat source is presented. Full-scale mock-ups were used to develop the procedures. A cylindrical metal block of Inconel X will be remotely loaded with an isotope at ORNL. The block will then be sealed and loaded into a specially designed cask and shipped by rail to the Martin nuclear hot cell facility, where the second phase of the operation will be conducted.

257 MND-P-2354
Martin Co. Nuclear Div., Baltimore.
NUCLEAR 1.0-WATT POWER SUPPLY FOR SPACE APPLICATION. Final Report [for] period covered: October 19, 1959–June 30, 1960. D. J. Knighton. June 1960. 54p. Contract AT(30-3)-217. OTS.

Activities in a program to analyze and design a 1-watt(e) power-supply system consisting of a radioisotope-powered generator and a static voltage converter are described. The preliminary generator design was used to manufacture a breadboard device for testing, and the design and analysis of the converter were completed. Revisions of the preliminary generator design are also discussed.

258 (MND-P-2356) PRELIMINARY OPERATIONAL SAFETY REPORT FOR THE TASK 5.6 THERMOELECTRIC GENERATOR. Daniel Knighton (Martin Co. Nuclear Div., Baltimore). May 1960. 54p. Contract AT(30-3)-217.

The operational hazards associated with the use of a plutonium-fueled thermoelectric generator in a terrestrial satellite are evaluated. It appears that the plutonium fuel can be consumed and dispersed at high altitude during reentry, following a successful mission. As an alternative, however, since the fuel (Pu^{238}) is an alpha emitter with a long half life, it appears that random intact reentry following a successful mission is feasible. As a precaution against aborted missions, the launch azimuth should be over water as much as possible to avoid impact or dispersion in areas of significant population density. It is recommended that the fuel and generators be transported by air carrier to preclude local restrictions of ground transport and to provide better statistical safety. The transport phase poses a very minor safety problem.

259 (MND-P-2366) CURIUM FUELED GENERATORS FOR LUNAR AND SPACE MISSIONS. Preliminary Safety Analysis Report. Cecil O. Riggs (Martin Co. Nuclear Div., Baltimore). June 1960. 55p. OTS.

Two thermoelectric generators that use Cm^{242} as the heat source are described. One, designed for a lunar mission, is fueled with 3.76 g of Cm^{242} with an activity of 12,480 c. The second, designed for a satellite or space probe mission, is fueled with 6.28 g having an activity of 20,400 c. Preparation of the fuel, assembly of the generator, and the launching of the vehicle are considered. Accidents that may occur in the launching of the vehicle are analyzed and the fate of the fuel in the event of an aborted mission or upon reentry of the vehicle after the completion of a mission are determined.

260 MND-P-2372
Martin Co. Nuclear Div., Baltimore.
DEVELOPMENT OF A THERMOELECTRIC OPTIMIZATION CODE FOR THE IBM-709. T. S. Bustard and W. C. Lyon. July 1960. 142p. Contract AT(30-3)-217. OTS.

The Thermoelement Optimization Method is an IBM 709 FORTRAN code which will, by means of automatic computation, perform a thermoelement analysis. Given hot and cold junction temperatures, thermoelectric material properties, and desired electrical output characteristics, it calculates the number and size of the thermoelements, the required thermal input, thermoelectric efficiency, and the electrical characteristics of the generator. Hot-junction contact resistance and Thomson effects may be taken into account or neglected, as desired. The basic calculation technique, as built into the code, may be briefly described as an adjustment of the thermal and electrical paths through the thermoelectric material under consideration in order to attain maximum material efficiency. The differential equation accurately describing the thermoelectric effects was obtained as an energy balance over an incremental segment of an element, and its solution was determined by a numerical technique. Temperature-dependent properties are therefore considered as variables rather than treated as over-all averages, which is the usual calculation technique.

261 (MND-P-2373) 13-WATT CURIUM FUELED THERMOELECTRIC GENERATOR FOR A SIX-MONTH SPACE MISSION. Final Report. Justin L. Bloom. Martin Co. Nuclear Div., Baltimore. July 1960. 46p. Contract AT(30-3)-217. OTS.

The development of a design concept for a thermoelectric generator suitable for use in extraterrestrial space missions for periods up to six months is outlined. The generator derives its power from the radioactive decay of the isotope Cm^{242}. It was optimized on the basis of minimum weight consistent with environmental safety and performance requirements. It weighs about 16.6 pounds and produces 13 watts of d-c power (at 3 volts output) continuously over its six-month operational life.

262 MND-P-2374
Martin Co. Nuclear Div., Baltimore.
13-WATT CURIUM-FUELED THERMOELECTRIC GENERATOR FOR HARD LUNAR IMPACT MISSION. Final Report—Subtask 5.8. Justin L. Bloom. Aug. 1960. 57p. Contract AT(30-3)-217. OTS.

Results of a conceptual design study for a curium powered thermoelectric generator of minimum size and weight which is capable of sustaining hard impact is presented. The generator produces a minimum of 13 watts of d-c power at 3 volts, and weighs 6.2 pounds excluding shielding.

263 MND-P-2399
Martin Co. Nuclear Div., Baltimore.
SUMMARY REPORT OF THERMIONIC ISOTOPIC POWER SYSTEM THROUGH JUNE 30, 1960. Robert J. Harvey. 535p. Contract AT(30-3)-217. OTS.

The objective of the work to develop a thermionic generator was to establish feasibility by fabricating and testing a low-power isotopic-fueled thermionic power system. The research phase, which consisted of work from the most basic and fundamental principles up through and including the testing of a two-stage generator with design features considered practical for an isotopically fueled power system, is reported.

264 MND-P-2413
Martin Co. Nuclear Div., Baltimore.
BIBLIOGRAPHY OF SNAP REPORTS. Aug. 1960. 9p. Contract AT(30-3)-217. OTS.

A listing is presented of documents, films, slides, and those items which were formally produced for utilization by the AEC concerning the SNAP project.

265 (MND-P-2726) SNAP PROGRAMS. M-1 MONTE CARLO RADIOISOTOPE SHIELDING CODE. Final Report. M. J. Kniedler (Martin Co. Nuclear Div., Baltimore). May 1, 1962. Contract AT(30-3)-217. 164p.

The M-1 code is a Monte Carlo code that applies to cylindrical geometry when solving for the flux from a prespecified radiation source. The source is a gamma and beta emitter and the solution is for the flux of each energy group and of each region of interest in regard to the emitter. A region is a volume of the system bounded by two planes perpendicular to the axis of symmetry and two cylinders (one cylinder if the region includes the axis of symmetry). The code can be used to solve for a maximum of 30 energy groups and 280 regions. The M-1 is coded in Fortran for a 32,000-word 7090 and requires that the energy intervals be prespecified as well as a complete description of the geometry of the system. A specification of materials in the system must also be given. The number of particles to be followed must be specified by the user. Since the technique of splitting can be employed here and so that splitting can occur, a description of the manner in which the system is divided (geometrically) must also be given by the user. A detailed description of the input required by the code is included. The dose per unit volume due to bremsstrahlung gammas for each prespecified region, and due to nonbremsstrahlung gammas for each prespecified region can be computed by the code. The total dose per unit volume for each prespecified region and the number of mean free paths traveled per second in each prespecified region for each energy group can also be computed along with the gamma flux for each prespecified region and for each energy group and the region volume associated with these parameters.

266 (MND-P-2953) SNAP PROGRAMS-UPPER ATMOSPHERE EXPERIMENTAL RE-ENTRY STUDY. Final Summary Report. William Hagis (Martin-Marietta Corp. Aerospace Div., Baltimore). Apr. 1963. Contract AT(30-3)-217. 86p.

An experimental flight test was made to verify and improve the methods and techniques used to predict the aerothermodynamic effects on re-entering SNAP devices. The amount of aerodynamic heating as a function of body shape, size, and mode of entry was indicated. Test specimens yielded trajectory, aerodynamic heating data, heat distribution, and heat transfer of known bodies. IBM 7090 digital programs were utilized and so constructed that one digital code complemented the other, i.e., at any time during the re-entry period, the complete thermal history of the body is known. The test specimens consisted of lead bodies containing alkali metals, used as flaring material, and a larger titanium cylinder containing telemetry equipment to monitor the exterior and interior wall temperatures during re-entry. By judicious placement of transducer sensors, aerodynamic heating rates and mode of entry, i.e., tumbling, spinning, and/or stabilized, were determined. The lead bodies were consumed at high altitudes whereas the telemetry capsule survived re-entry.

267 (MND-P-2975) CHARACTERISTICS OF FUEL COMPOUNDS AND ENCAPSULATION MATERIALS IN RADIOISOTOPE HEAT SOURCES. (Martin-Marietta Corp. Aerospace Div., Baltimore). Apr. 17, 1963. Contract AT(30-1)-2345. 19p.

The properties of radioisotope fuel compounds and fuel capsule materials which are pertinent to the design and operation of radioisotope heat sources are outlined. These properties are grouped into the following categories: intrinsic, extrinsic, and compatibility. The properties of strontium titanate as the fuel and Hastelloy C as the capsule material are evaluated.

268 (MND-P-3014-I) SNAP RADIOISOTOPE SPACE PROGRAMS; TASK 7. Quarterly Progress Report No. 6, January 1 through March 31, 1961. (Martin Co., Nuclear Div., Baltimore). Contract AT(30-1)217. 72p.

Results of radioisotope flight safety analyses and tests are presented. Safety study of a typical Cape Canaveral launch, study of a lunar impact of a radioisotope-fueled thermoelectric generator, upper atmosphere experimental re-entry studies, fuel core heating and ablation, generator burnup, high altitude sampling, and radioisotope shielding code are discussed.

269 (MND-P-3014-II) SNAP PROGRAMS. THERMIONIC ISOTOPIC POWER SYSTEMS. Quarterly Progress Report No. 6, January 1 through March 31, 1961. (Martin

Co Nuclear Div., Baltimore). 101p Contract AT(30-3)-217

Progress in thermionic technology necessary for the development of power supplies utilizing radioisotopes as heat sources is reviewed. An investigation was made of the characteristics of cesium-filled thermionic converters operating in the low temperature region. Parametric studies were made of the cesium diode with a tantalum emitter and no back emission and operational characteristics were determined in the collision-free region Work was continued on the vacuum diode generator, with emphasis on the development of Generator 2B Several significant design changes were made The sapphire spacer rods were replaced by a peripheral ring support to provide the desired inter-electrode spacing Preliminary tests indicated that the use of an oxidized molybdenum collector may be an effective way of attaining and maintaining a collector work function less than 1.9 volts. Studies were begun to design an encapsulated Cm^{242} heat source suitable for fueling the vacuum diode generator Materials selected to be evaluated for the fuel container were molybdenum, tungsten, and tantalum alloys

270 (MND-P-3014-III) SNAP PROGRAMS. Quarterly Progress Report No. 6, January 1 through March 31, 1961. Task 6. Fuel Technology Development Program. (Martin Co. Nuclear Div., Baltimore). Contract AT(30-3)-217. 72p.

Isotope power sources are being developed for use in thermionic and thermoelectric power generators for space applications. Suitable radioisotope fuels and heat source containment capsules are being designed for SNAP-type generators with land, sea and space applications. Curium-242 and Plutonium-238 are currently being investigated, and methods for purification, compound conversion and fuel form are being established. A Heavy Elements Processing Facility capable of handling and preparing gram quantities of Am^{241} in an aluminum matrix for irradiation to Cm is being activated. In the facility, high integrity aluminum capsules were produced through special encapsulation and welding techniques. Curium purification by ion exchange techniques is under study to determine the operating conditions and design parameters for the Hot Cell Facility. Following a screening process, these container materials were selected for further investigation· Hastelloy C and Inconel X for thermoelectric applications and a Mo-W combination for the curium thermionic generator. Safety, thermal and shielding analyses were conducted on the processes being developed as well as during handling and shipping.

271 (MND-P-3015-II) THERMIONIC ISOTOPIC POWER SYSTEMS, SNAP PROGRAMS. Quarterly Progress Report No 7, Covering Period April 1 through June 30, 1961 (Martin Co Nuclear Div , Baltimore) Contract AT(30-3)-217 76p

An extensive parametric study of cesium-filled converters was completed during the quarter Cesium-filled test units Nos. 2 and 3 were designed and constructed, and Unit 1 is 85% complete. The prototype vacuum thermionic converter, Unit 2B, was subjected to dynamic testing following its failure due to emitter poisoning. The analysis and design of the curium fuel capsule were completed

272 (MND-P-3015-III) SNAP PROGRAMS TASK 6—FUEL TECHNOLOGY DEVELOPMENT PROGRAM. Quarterly Progress Report No. 7, April 1 through June 30, 1961. (Martin Co. Nuclear Div., Baltimore). Contract AT(30-3)-217. 62p.

Progress made in the development of isotope power sources for thermoelectric and thermionic conversion to electrical energy is reported. The Heavy Elements Processing Facility for processing americium and fabricating americium capsules for irradiation was opened and hot operation was begun. Modifications to the americium purification system were completed and checkout operations were begun Process specifications were established for dissolution of the irradiated capsules and the major equipment for this operation was designed. Experimental work on the purification of curium was continued. Blending and crushing studies were conducted to establish techniques and procedures for preparing curium carbide and for producing homogeneous cermet fuel forms. Investigations were also made into the compatibility of various matrix and container materials with curium carbides and oxides. Flow diagrams for the fuel form and isotope encapsulation processes were completed. A safety analysis was conducted which verified the integrity of the americium capsules during all stages of the irradiation program.

273 (MND-P-3017-I) SNAP RADIOISOTOPE SPACE PROGRAMS QUARTERLY PROGRESS REPORT NO. 9, OCTOBER 1 THROUGH DECEMBER 31, 1961. (Martin Co. Nuclear Div., Baltimore). Contract AT(30-3)-217. 17p.

All Phase I and Phase II testing was completed. Both launches of Phase I were successful, neither Phase II launches were successful. Test data recovered on Phase I launchings included optical coverage of re-entry and the trajectory and weather data; no telemetry canister temperature data were obtained. No test data were obtained on Phase II experiments Reduction of Phase I test data was begun. The Phase II (Sub-subtask 7.3.2) was terminated December 20, 1961, when no test data were recovered for comparison with the analytically predicted results The Sub-subtask 7 3.3 program (Generator Re-entry Burnup Study) was completed and terminated December 29, 1961 The study objectives were met. The Sub-subtask 7 3.4 program (High Altitude Sampling) was terminated when it was completed November 30, 1961. All study objectives were met. Topical reports were prepared on Sub-subtasks 7.3.1, 7.3.2, 7.3.3 and 7.3.4 in December 1961. Information on the work performed in the reporting period that was not included in the topical reports is included. Checkout and troubleshooting operations on the last two subroutines and main radioisotope shielding code were completed. Results from several runs of a simple check problem compared well with published data.

274 (MND-P-3018-I) SNAP RADIOISOTOPE SPACE PROGRAMS QUARTERLY PROGRESS REPORT NO 10, TASK 7, JANUARY 1 THROUGH MARCH 31, 1962 (Martin Co Nuclear Div Baltimore). Contract AT(30-3)-217. 21p

In the absence of reduced test data from the upper atmosphere re-entry study for the comparative analysis of actual test results and predicted results, effort was expended in review of raw data to recover information not previously uncovered. A review of the K-24 film disclosed that its reading with a densitometer could prove beneficial, in addition, the mechanical errors responsible for the poor quality of data recorded were revealed in sufficient time for corrective measures to be taken for any subsequent testing Review of spectral photographs disclosed faint second-order characteristic lines which, possibly, will permit identification of the test specimens by the flare materials they contained. The telemetry canister was redesigned to accommodate an operational antenna on the test, modification of the canister was initiated. An analysis of code-calculated dose rates from the Sr^{90} weather station generator resulted in better correlation than previously achieved. A doubling technique wherein unabsorbed particles were split after traveling at least three mean free paths was incorporated into the code for these runs.

275 (MND-P-3019-I) SNAP RADIOISOTOPE SPACE PROGRAMS. Quarterly Progress Report No 11, April 1 through June 30, 1962. Task 7. (Martin Co Nuclear Div., Baltimore). Contract AT(30-3)-217. 21p.

The reduction and analysis of data from two re-entry heating tests on simulated SNAP fuel cores were completed. Important points in the analysis are presented Identification of one test specimen gives support to the following significant conclusions the computational techniques used in re-entry analysis are highly accurate and the design theory applied to the design of SNAP flight hardware for burnup is conservative. Preparations for a third fuel core ablation test were concluded. For this test, data collection and reduction methods were improved through changes in the telemetry canister, the fuel-simulating alkali metals, changes in camera filters, and modification and calibration of test equipment.

276 MND-SR-1672
Martin Co. Nuclear Div., Baltimore.
STRONTIUM-90 POWER PROJECT QUARTERLY PROGRESS REPORT I. Jan. 1959. 62p. Contract AT(30-1)-2281. OTS.

The purpose of the Sr^{90} contract is to design an apparatus capable of converting the radioisotopic decay energy into a useful source of electrical power. The apparatus must have a safe, long, unattended life. Two designs will be produced during the contract study, one for land application and the other for sea application. In addition to these conceptual designs, an inoperative model will be constructed to illustrate a possible design of the land-based application. The first quarter of the Sr^{90} program was concerned with construction of the model, investigation of possible compound forms of Sr^{90}, cladding requirements, selection of energy conversion, and biological shielding. Required laboratory materials and reagents were procured as well as a small furnace, ball mill and a press for use in a fume hood Special apparatus such as a contained corrosion test assembly for Sr^{90} tracer experiments was fabricated. Stable as well as tracer experiments are in progress to determine the corrosion resistance of various compound forms of Sr in hot and cold fresh and sea water. Similar tests are being conducted on cladding materials such as Mo, Ta, W, and Ni. Compound forms of Sr are being studied as pure ceramics, ceramics with non-metallic additives, and cermets. Cladding requirements such as element insertion and lid welding are under test. The problem of heat transfer, including a method employing helium gas under 12 atmospheres of pressure, is being analyzed. Thermal conductivity and stress measurements are 50% completed on those compounds of strontium still under examination. Of the original six compounds of strontium considered (plus two additional) five compounds were eliminated and three are still under test. Those still being tested are strontium boride, strontium titanate, and strontium zirconate. A model of the land based application is being completed. It incorporates strontium boride as the heat element compound and lead telluride thermoelectric materials for conversion of heat into electricity. A biological shielding determination was made for the land based conceptual design at Brookhaven National Laboratory. For this work, a 100-channel pulse height analyzer was employed. Tests showed that bremmstrahlung generated within the heat elements would be in the low kilovolt region and would be attenuated by the element and heat accumulator. Only those beta particles escaping from the outer 1/4 inch and impinging upon the cladding would generate hard gamma radiation. A statistical evaluation of thermal conductivity from the heat elements outward and through the cladding, heat accumulator to the finned biological shield is in progress.

277 MND-SR-1673
Martin Co. Nuclear Div., Baltimore.
STRONTIUM 90 POWER PROJECT. Quarterly Progress Report [for] January 15, 1959 through April 15, 1959. Apr. 1959. 90p. $15.30(ph), $5.40(mf) OTS.

The purpose of this program is to determine the feasibility of using Sr^{90} as the heat source in a thermoelectric generator which is to have an unattended life expectancy of up to 10 years under the most extreme environmental conditions. Designs for 100-w generators for land, sea, and undersea applications are being developed. The most suitable compound form of Sr^{90} and the most corrosion resistant alloy for both land and sea applications were selected, and biological shield requirements were determined. The land application design was completed, and fabrication problems of such a unit were analyzed. In selecting the most suitable compound form of Sr^{90}, eight compounds were tested for insolubility, thermal conductivity, fabricability, high compound density, high strontium density, and structural stability. Of these eight, only strontium titanate exhibited the qualities required. The corrosion box for heat element compound evaluation was fitted with a water reservoir system to provide constant volume during long term studies. The heat element fabricating dry box was fitted with rubber glove ports and an automatic air sampling device to assure safe operating conditions for fabricating test pellets containing Sr^{90}. Stable strontium titanate pellets as large as 2 5/8 in. in diameter were successfully fabricated. Thermal conductivity of strontium titanate and cermets of this compound are being measured from room temperature to operating temperatures of the proposed generator. (First quarterly progress report was administrative in nature and is not available for public release.)

278 MND-SR-1674
Martin Co. Nuclear Div., Baltimore.
STRONTIUM 90 POWER PROJECT. Quarterly Progress Report III covering period April 15, 1959 through July 15, 1959. July 1959. 79p. Contract AT(30-1)-2220, Task II. OTS.

As a result of information received from ORNL, early strontium titanate heat elements may contain macro quantities of stable Ca and Ba. Since these contaminants could affect the solubility of strontium titanate to the detriment of safe containment, test heat elements were prepared containing varying amounts of these elements. In addition to solubility measurements in fresh and sea water, samples are being examined to determine the physical properties of this new mixture. The ceramic investigation showed that heat elements made from pure strontium titanate would be superior to any cermet of that compound. Metal additions below 30 wt. % had no effect on thermal conductivity and did, in some cases, increase the solubility of the heat element by forming soluble complex compounds with the otherwise insoluble strontium titanate. The process for fabricating strontium titanate heat element increments was refined to produce uniform pellets of optimal density, homogeneity, and Sr tie up. To assure future availability of pure Sr^{90} in kilocurie quantities, the separation of this waste fission product is under laboratory scale investigation by ion exchange. Data compiled on the physical and chemical properties of strontium titanate are completed. Results indicate that this choice of heat element compound will possess those properties required for the safe utilization of a Sr^{90} heat source. The thermal conductivity of this compound decreases only slightly with increased temperature, thereby assuring a generator core that will not melt on accidental temperature excursion. The solubility of strontium titanate in fresh and sea water was measured over a period of 100 days. At the end of this time there was absolutely no strontium detectable in the fresh water and only 10 ppb in the sea water. Such information indicates that unclad strontium titanate heat elements would require centuries to dissolve, during which time natural radioactive decay would have reduced kilocurie quantities of Sr^{90} to the millicurie level. A modified sea design with a removable biological shield will make possible the use of this power supply in marine environments where weight is a critical factor. This unit will employ less Sr^{90} with longer thermocouples. The operational shell will be of sufficient thickness to be resistant to deep sea pressure. During storage, it will be encased in a second nickel shield with a liquid metal film between to act as a heat transfer agent. It is anticipated that both sea application devices will operate at approximately seven percent efficiency. Hazards evaluation of the land-based application is in progress. Both structural and radiation integrity are being evaluated. Data obtained during the experimental phases have been interpreted to determine the resistance of a Sr^{90} generator to natural and man-made disasters. (For preceding period see MND-SR-1673.)

279 MND-SR-1675
Martin Co. Nuclear Div., Baltimore.
STRONTIUM 90 POWER PROJECT. Quarterly Progress Report No. IV covering Period July 15, 1959 through October 15, 1959. Oct. 1959. 123p. Contract AT(30-1)-2220, Task II. OTS.

Work aimed at optimizing the fabrication process for manufacturing strontium titanate pellets was completed. It was determined that the quality and insolubility of such pellets depend upon a pure starting material and that any increase in stable contamination can adversely affect the desirable properties. A second ball milling step was incorporated into the blending process to assure fine particle size and complete Sr tieup in the firing operation that follows. Sample pellets prepared from 8 different batches of starting material all resulted in densities above 94% of theoretical. Diameter shrinkage varied from 19 to 21%. Time span in excess of two weeks between calcining and firing was shown to positively decrease final pellet density. Stable corrosion testing of those samples prepared during the ceramic study was completed. Tracer studies of the absolute solubility of Hastelloy C are described. Two conceptual designs were completed for the 100-watt sea-based generator. One design is similar to the land-based device but employs 280,000 instead of 320,000 curies. The second design features a removable biological shield for sub-sea use. Shock, vibration, radiation, and selective atmosphere test units were fabricated and loaded with lead telluride thermocouples. A conceptual design for a land-based 5-watt generator was completed. (For preceding period see MND-SR-1674.)

280 MND-SR-1676
Martin Co. Nuclear Div., Baltimore.
STRONTIUM 90 POWER PROJECT. Final Summary Report for October 15, 1958 through February 29, 1960. Mar. 1960. 142p. OTS.

A chemical compound was produced that rendered Sr^{90} insoluble in many media. This compound is $SrTiO_3$, which when tested in 0.1 N acid or base for 750 hr at 120°F showed 5 ppm or less solubility by flame-photometer tests. In demineralized, tap, or sea water, the solubility of a $SrTiO_3$ pellet is extremely low. By tracer experiments with Sr^{90} mixed into the $SrTiO_3$ pellets, it was found that no activity was present in tap water after 2400 hr of testing at 150°F. With natural sea water after 2448 hr at 150°F, the average fraction of $SrTiO_3$ dissolved was 0.0003. At this rate, it would take over 900 yr to dissolve the pellet tested. Additional experiments were conducted with as much as 25% impurities of Ca-Ba without destroying the $SrTiO_3$ ceramic linkage throughout the pellet. Experiments show that insoluble ceramic pellets of $SrTiO_3$ can be clad with a corrosion-resistant metal for increased protection. Such a metal was found in Hastelloy C which, when tested in ocean water for 10 years, showed a corrosion rate of only 0.0001-in. per year. In addition, Hastelloy C does not pit in sea water and can be welded with a Hastelloy C welding rod. Hastelloy C, 1/4-in.-thick, would resist penetration of sea water for thousands of years. If triple packaging in Hastelloy C were employed, an almost indestructible package of $SrTiO_3$ pellets could be prepared for use in sea water with absolute safety. With lead telluride thermocouples utilized within the package, the assembled unit could produce usable amounts of electrical power. Conceptual designs were prepared for two 100-watt electrical generators for use on land or in sea water, and a 5-watt electrical generator for use with an automatic weather station. Models of both the 5- and 100-watt generators were prepared. Environmental tests of thermoelectric elements were conducted while operating at design temperatures and being irradiated by high-energy γ rays. Results indicated satisfactory performance. Vibration and shock tests were also performed with thermoelectric elements. One-half-in.-dia. elements successfully passed all vibration and shock tests. The 0.187-in.-dia. elements had difficulty with the 15-g loadings. However, it is felt that a revised design may pass the more stringent tests. Power production during vibration was slightly lowered, but after testing, the power generation returned to normal. (For preceding period see MND-SR-1675.)

281 (MND-SR-2259) 5-WATT RADIOSTRONTIUM GENERATOR FOR AN UNATTENDED METEOROLOGICAL STATION. HAZARDS SUMMARY REPORT. C. O. Riggs (Martin Co. Nuclear Div., Baltimore). Feb. 1960. 53p.

It is noted that the chief potential radiological hazards posed by radiostrontium are direct external radiation exposures, and internal radiation exposures as a consequence of ingestion and inhalation. The conclusions to be derived from the analysis are that containment for the strontium titanate is maintained under all credible accidents and that the relative insolubility of the fuel minimizes internal exposure even if it is released to the biosphere under incredible circumstances.

282 (MND-SR-2308) 100-WATT RADIOSTRONTIUM GENERATOR FOR LAND- AND SEA-BASED APPLICATIONS. HAZARDS SUMMARY REPORT. C. O. Riggs (Martin Co. Nuclear Div., Baltimore). Mar. 1960. 34p.

The radiostrontium generator produces 100 electrical watts from radioactive beta decay energy which is converted thermoelectrically. The fuel is 320 kilocuries of strontium-90 with a half-life of 28 years for the land-based concept and 280 kilocuries for the sea based version. The fuel form is strontium metatitanate ($SrTiO_3$), a relatively insoluble, chemically stable compound. The fuel pellets are enclosed in a fuel container placed in a multivessel containment. The land-based concept uses 120 pairs of lead telluride thermoelectric elements and the sea-based one uses 132. These are placed against a heat accumulator and operate at hot junction temperatures of 529 and 512°C in air, respectively. The cold junction temperatures are 140 and 123°C, respectively. At present, Strontium-90 is a nuclear waste material derived from spent reactor fuel that is processed at Oak Ridge National Laboratory. Strontium titanate is made by stoichiometrically compounding strontium with titania, sintering and pelletizing at 5 tsi pressure. Solubility studies of strontium titanate have indicated relative insolubility Biological shielding against the direct radiation of the heat source is provided by a Hastelloy C shield which also serves as an outer containment vessel The fuel emits beta, x and gamma radiation. The prototype generator will supply power for an unattended marine power source and various land applications. The precautions against radiation exposure inherent in the generator are multiple containment, biological shielding, and an insoluble fuel. The generator is designed within the framework of all credible accidents.

283 (MND-SR-2615) DATA TELEMETRY PACKAGE POWERED BY STRONTIUM-90 FUELED GENERATOR. Final Report. (Martin Co. Nuclear Div., Baltimore). Sept. 1961. Contract AT(30-1)-2519. 206p.

An automatic, nuclear powered, meteorological data transmitting radio station was designed and fabricated for unattended service at a remote Arctic location. The system automatically measures air temperature, barometric pressure, wind direction, and two wind speed averages. Once every three hours it transmits this data in binary digital form, on two frequencies, to a manned receiving station (also designed as a part of this contract) where it is recorded on a two-channel recorder Temperature, wind direction and barometric pressure are read at the instant of transmission; wind speed is averaged during an eight-minute interval and a one-minute interval immediately preceding transmission. A five-watt thermoelectric generator was designed, manufactured and electrically tested for a period of 8.5 months. In May 1961, the generator was fueled with a capsule containing 17,500 curies of Sr^{90}. Electrical performance tests were conducted with the integrated system of generator, converter and batteries prior to isotope loading and also after Sr^{90} fueling operations. Weather station compatibility tests were performed in June 1961 and the complete power supply and station housing were packaged for overseas shipment in July 1961. Current residence of the Sr^{90} generator is on Axel Heiberg Island in the Arctic region.

284 (TID-18323) RADIOISOTOPE-FUELED POWER SUPPLIES. Lecture Presented at University of California, Los Angeles, California, UCLA Short Course, Space Power Systems, July 17-28, 1961. J. G. Morse (Martin Co., Baltimore). 133p. Contract AT(30-3)-217. 133p.

Considerations that permit selection of a radioisotope that meets the complex requirements of the desired power supply are discussed. Methods of separation and purification of useful isotopes are outlined. Brief mention is made of the principles of direct conversion of heat to electricity. Design approaches for isotopic power units are described. A delineation of the approach to the solution of the nuclear safety problem is made, followed by predictions for the future of isotopic power. Sample problems of the type solved in the SNAP program are given.

285 (WADD-TR-60-699(Vol.XI)) ENERGY CONVERSION SYSTEMS REFERENCE HANDBOOK. VOLUME XI. RADIOISOTOPE SYSTEM DESIGN. (Martin Co., Baltimore <u>and</u> Electro-Optical Systems, Inc., Pasadena, Calif.). Sept 1960. Contract AF33(616)-6791. 315p. (EOS-390-Final (Vol.XI))

Direct-conversion, nuclear-powered thermoelectric auxiliary power units offer promise for space vehicle applications because of their reliability and simplicity Radioisotopes suitable for fueling these units will become more plentiful in the future from by-products of other nuclear programs. Extensive research and development work was carried out on isotopic-powered generators This work in basic technology, radiation safety, and specific equipment design is described Basic work includes methods of preparation and containment of fuels, energy conversion systems, and generator design principles. Prevailing concern over radiological hazard is answered by discussion of each possible hazard situation from gound handling to various vehicle missions, including aborts. Five practical generator designs are presented including SNAP IA, a 125-watt, one-year generator using Cerium-144, and the Polonium-fueled SNAP III, both of which have progressed to the advanced hardware stage. A comparison of nuclear- and solar-powered generators indicates some advantage for the nuclear device for requirements of less than 1 kwe when the mission involves long periods of flight away from the sun.

286 NUCLEAR ENERGY IN SPACE–RADIOISOTOPE AUXILIARY POWER SYSTEMS. Jerome G. Morse and Douglas G. Harvey (Martin Co., Baltimore). Aero/Space Eng., 20· No. 11, 8-9, 58-62(Nov. 1961).

The radioisotope auxiliary power systems to be used in space are discussed. Included in this discussion are typical radioisotopic heat sources and the specifications for several of the SNAP generator systems. The re-entry into the earth's system, cost, safety, and future of the systems are also discussed.

287 SNAP RADIOISOTOPIC POWER SYSTEMS. J G. Morse (Martin Co., Baltimore). IRE Trans. on Nuclear Sci., NS-9 34-44(Jan 1962).

Auxiliary power systems deriving their energy from radionuclide decay are under development Called SNAP, the program was oriented toward satisfying the need for small, compact, lightweight, and reliable power supplies for space systems. Radioisotopic power relates to the generation of heat by absorption of electromagnetic and particulate radiations emitted by a carefully sealed source of radioisotopes. The heat is then partially converted into electricity by a thermoelectric or thermionic conversion device, with the remainder rejected to the external environment. A status report on SNAP radioisotopic devices is presented. Some of the unique aspects of the technical problems encountered are explored. Since these power systems have no moving parts, they lend themsleves appropriately to the performance of the following types of space missions satellites operating on equatorial orbits, satellites operating for considerable periods of time in the Van Allen radiation belts, lunar explorations, venus surveys, and space probes away from the sun. Auxiliary power systems capable of fulfilling the demands of these missions with radioisotope source are described.

288 NUCLEAR AUXILIARY POWER UNIT FOR LUNAR EXPLORATION Alan J Streb, Robert J. Wilson, and Thomas S Bustard (Martin Co , [Baltimore]) IRE Trans on Nuclear Sci , NS-9 85-90(Jan 1962)

Unmanned soft lunar landing experiments by the United States are currently being planned by the National Aeronautics and Space Administration. All of these experiments will require some form of electrical power, and their success or failure will depend upon the development of a suitable, reliable electrical power generation system The system utilized must be compact, lightweight, and rugged Certain requirements for such an experiment could be met by solar cell arrays The reliability of solar cells was well established, however, their usefulness for this mission is inherently limited Experiments conducted during the lunar night require a large storage capacity, if solar energy is to be the spacecraft's only source of power A radioisotope-fueled thermoelectric generator can fulfill all spacecraft power requirements continuously throughout the lunar day or night without special orientation A radiosiotope, such as Cm^{242}, may be used as the thermal energy source for lunar experiment of short duration (90 to 120 days) Cm^{242} does not occur in nature, but may be created by the neutron irradiation of Am^{241} This radioisotope requires very little radiation shielding to protect sensitive equipment, because of the low gamma flux associated with its decay The rigors of the lunar "climate" produce an environment which present-day electronic equipment will not tolerate By utilizing waste heat from the radioisotope generator, the electronics compartment temperature may be controlled within acceptable limits All subsystems within the generator may be duplicated to improve its reliability This duplication, combined with the inherent dependability of static conversion, results in a system with a very high over-all reliability Such a system can be developed for a soft lunar landing experiment within current state-of-the-art capabilities

289 RADIONUCLIDE POWER SOURCES J G Morse (Martin Marietta Corp , Baltimore) J Brit Interplanet Soc , 19 87-92(May-June 1963)

A review is given of the fundamental characteristics of power sources in which the decay heat of a radioisotope is converted into electricity by some direct energy conversion device—a thermoelectric converter in present devices Some work carried out in the U S Atomic Energy Commission's SNAP Program is described, including experiments to study operational safety and particular sources developed for the Transit and communications satellites and for the Surveyor lunar probe

290
ELECTRICAL GENERATION BY DIRECT CONVERSION USING ISOTOPES. E. R. Ningard and H. O. Banks (Martin Co., Baltimore). Nuclear Sci. and Eng. 2, No. 1, Suppl., 151-2(1959) June.

Isotope-powered generators present an attractive method of converting decay heat of radioisotopes into useful electric power. Strontium-90 and lead telluride have been chosen for the power sources and thermoelectric materials. Two studies are reported; one covers a 100-w design for land or sea application and the other a parametric study of space power applications for optimization of conditions. To provide 2000 watts of thermal power, 15 kg of Sr^{90} will be employed as a strontium titanate-chromium cermet. The present design consists of seven strontium titanate cylinders with cladding placed in a circular arrangement in a cylindrical block, which serves as the heat source.

291 THE TECHNOLOGY OF RADIOISOTOPIC POWER J G Morse (Martin Co , Nuclear Div Baltimore) Proc Japan Conf Radioisotopes, 5th, No 3, 296-302(1963) (In English)

Power systems deriving their energy from radionuclide decay have been under development for more than six years under U S Atomic Energy Commission sponsorship Called SNAP, these systems consist of large sealed sources of radioisotopes which generate heat through absorption of decay energy Power is obtained by converting this heat into electricity using thermoelectric and thermionic devices The physical chemical and nuclear characteristics of appropriate radioisotopes as they relate to the design of optimum thermoelectric generators are reviewed The uniqueness of these power systems lies in their use of radionuclide heat and their design life-times are determined in large part by the decay rates of the high power density fuel materials During the past year a number of radioisotopic power systems have proved to be practical devices for uses in remote locations Technical considerations are described which relate to the selection of the fuel power density (thermal watts per cubic centimeter) of the chemical form used operating temperatures containment of fuel and safety of the system

292 ENERGY FOR REMOTE AREAS J G. Morse (Martin Marietta Corp , Baltimore). Science, 139 1175-80(Mar 22, 1963)

Radioisotope-fueled generators are being used to supply power in small terrestrial and space systems The fuel choice, energy conversion system, and effects of environment on the generator design are discussed Various generators now in operation or under development are described

293 RADIOISOTOPES FOR SPACE RE-ENTRY TESTS AND PARTICULATE STUDY Charles R Fink (Martin Co , Baltimore), Douglas G Harvey, and Charles M Barnes Trans Am Nucl Soc , 5 443-4(Nov 1962)

294 ISOTOPIC HEAT AND POWER. Douglas Harvey (The Martin Co., Baltimore).
p.68-77 of "Proceedings of the American Power Conference, March 29, 30, 31, 1960, Chicago, Illinois. Vol. XXII." Chicago, Illinois Institute of Technology.

A survey on radioisotopes as self-contained sources of power is presented in which some of the factors involved in radioisotopic power source design and some of their possible applications are described. A radioisotopic power source comprises a radioisotope fuel, an energy conversion device, and a heat sink. Some of the characteristics, e g , useful power density and half life, of promising radioisotope fuels are presented. The possible biological hazards of these fuels are discussed. An extensive testing program is under way for testing encapsuled radioisotopes under high impact and temperature conditions. Three forms of energy conversion devices are being considered: turboelectric, thermoelectric, and thermionic The characteristics of the SNAP III B generator, the prototype of space power sources, are presented, and some of the results of the vibration tests of this generator type are given; no failure or bad effects occurred for accelerations of 15 g lasting 5 min and of 50 g lasting 1 μsec. Thermoelectric power sources now are being designed for greater weight savings and lifetime, and thermionic sources are on the way. An extremely insoluble form of strontium was developed as a pelletized titanate for surface applications with small biological hazard. Specific surface applications are discussed, such as remote weather stations, mountain top radio and light beacons, buoys, and underwater use. Radioisotopes can also be used as heat sources, e.g., tube and battery heaters. It is concluded that radioisotopes make possible the construction of rugged power sources of long lifetime (6 months to 10 yr) in the power range 1 to 500 watts.

295 13-WATT ISOTOPE-POWERED THERMOELECTRIC GENERATORS FOR SPACE AND LUNAR IMPACT MISSIONS. Justin L. Bloom and James B. Weddell (Martin Co., Baltimore). Paper No. 1332-60. [Presented at the ARS Space Power Systems Conference, Santa Monica, California, September 27-30, 1960. New York, American Rocket Society, 1960]. 28p.

Two small thermoelectric generators that derive their power from the radioactive decay of Cm^{242} were designed. The first is intended for use in space and is capable of delivering an essentially constant power output of 13 electrical watts over a 6-month operational life. It weighs 16.6 lb and occupies a volume of 230 in^3. The second generator is designed to operate for 2 months, both in lunar day and night, after a hard (500 ft/sec) impact on the moon. The principles of design are described. The complete power supply weighs 6.2 lb and occupies a volume of 350 $in.^3$, including allowances for mounting structure and radiator surfaces. In both cases, external radiation levels may be reduced to the point where personnel exposure in ground handling and photon dosage to neighboring instrumentation are minimized. Thermal-to-electrical conversion principles, properties of the radioisotope fuel, method of encapsulation of the fuel and techniques for obtaining constant power output are discussed. Safety considerations in the event of accidents during launch-to-operation sequence are presented briefly.

296 SAFETY ANALYSES AND TESTS OF A RADIOISOTOPE POWERED THERMOELECTRIC GENERATOR. Paul J. Dick (Martin Co., Baltimore). Paper No. 1341-60. Presented at the ARS Space Power Systems Conference, Santa Monica, California, September 27-30, 1960. New York, American Rocket Society, 1960. 14p.

An interesting and important aspect in the development of a radioisotope-powered thermoelectric generator for space application includes the assurance of radiological safety under all operational conditions. The many facets of this work include: Hot-cell fuel-core loading, transportation of the radioisotope fuel core, fuel-core transfer to the generator, generator shielding, launch abort procedures, launch-pad-flight vehicle-failure conditions, launch-ascent-flight vehicle-failure conditions, and reentry from extra-terrestrial flight. The portion of an extensive safety program dealing with flight vehicle failure and reentry from orbital flight is discussed. In particular, the analyses and tests that were conducted to establish complete radioisotope fuel containment in the cases of vehicle failure on the launch pad, vehicle failure during launch ascent, and fuel burnup at high altitude in the case of reentry from orbital flight are highlighted. The various tests conducted to demonstrate a safe environment during the life of the radioisotope fuel are reviewed. Included in this summary are: high-velocity fuel-core impact tests, high-temperature fire tests, explosion and shock tests, LOX immersion tests, corrosion and material compatibility tests, and plasma jet reentry burnup tests.

297 NUCLEAR AUXILIARY POWER UNIT FOR LUNAR EXPLORATION. Robert J. Wilson, Alan J. Streb, and Thomas S. Bustard (Martin-Marietta Corp., Baltimore). Preprint No. SAE-515A. Prepublication Copy. 5p.

A radioisotope-fueled thermoelectric generator is ideally suited to the nighttime power requirements of unmanned soft lunar landing experiments. A generator design capable of producing 25 w of electric power as well as sufficient thermal energy for environmental control of critical electronic components is described. Sufficient curium-242 may be encapsulated to provide an operational life of 90 to 120 days in a unit weighing 30 lb. This unit will extend the data gathering capability of the experiment with a significant weight advantage over conventional power supplies.

Martin-Marietta Corporation, Denver, Colorado

298 ISOTOPIC HEAT AND POWER. Charles E. Crompton (Martin Marietta Corp., Denver). Preprint Paper No. 84. New York, Engineers Joint Council, 1962. 29p.

The design and performance of isotopically fueled direct conversion (thermoelectric) generators now in use and being constructed are reviewed. The use of fission products such as Sr^{90} and Cs^{137} is discussed together with the transuranic elements Pu^{238} and Cm^{242}. The major parameters affecting design and efficiency such as isotopic power density, shielding, thermoelectric materials, and heat transfer are reviewed. The paper endeavors to treat both the capabilities of today's systems and the problems that must be solved in building tomorrow's improved devices.

National Advisory Space Administration, Washington, D. C.

299 ELECTRIC POWER GENERATION IN SPACE BY SOLAR AND OTHER MEANS. Albert E. von Doenhoff (National Advisory Space Administration, Washington, D C.). p.237-58 of "Advances in Astronautical Propulsion." London, Pergamon Press, 1962.

Electric power generation in space is discussed. The means considered include chemical and nuclear as well as solar sources. Basic characteristics of each type are described, including an indication of the practical operational difficulties associated with each type of source. Means for converting heat and photon energy to electrical energy are described. These include mechanical systems using thermo-dynamic working fluids, thermoelectric devices, thermionic devices and photovoltaic devices. The characteristics and probable roles of each type are discussed. Some space power projects are described, including the solar power system for the Ranger series of spacecraft for lunar missions, the 3-kw Sunflower I solar power system and the SNAP VIII 30-kw nuclear power system.

National Aeronautics and Space Administration, Office of Programs, Washington, D. C.

300 RADIONUCLIDE POWER FOR SPACE PART 3. GENERATOR PERFORMANCE AND MISSION PROSPECTS. Fred Schulman (National Aeronautics and Space Administration, Washington, D. C.). Nucleonics, 21 No. 9, 54-8(Sept. 1963).

Future prospects for isotope power in space and the status of the technology upon which these prospects are based are pointed out Generator needs and performance in space are discussed with examples of present missions cited.

301 FIRST METEOROID-PENETRATION DATA FOR SNAP DESIGNERS. Charles T. D'Aiutolo (National Aeronautics and Space Administration, Washington, D. C.). Nucleonics, 21: No. 11, 51-5(Nov. 1963).

Data are presented from the latest experiments on meteoroid penetration from Explorer XVI. The results show that the probability of penetrating metal sheets with thicknesses around 0.0025 cm is considerably less (10 to 100 times) than designer estimates.

302 THE NASA NUCLEAR ELECTRIC POWER PROGRAM. Fred Schulman (National Aeronautics and Space Administration, Washington, D. C.). ARS Preprint No. 2522-62. New York, American Rocket Society, 1962. Prepublication Copy. 11p. $1.00.

The projected requirements and capabilities for space electric power in the ranges below 0.5 kw, on the order of 10 kw, and on the order of 10 Mw are discussed. The uses of radioisotope, reactor, and advanced systems to fulfill the requirements are outlined.

National Research Council. Materials Advisory Board, Washington, D. C.

303 (MAB-177-M) REPORT BY THE COMMITTEE ON MATERIALS ASPECTS OF AUXILIARY POWER UNITS FOR USE IN SPACE VEHICLES. (National Research Council. Materials Advisory Board). Oct. 25, 1961. 159p

Materials problems associated with power conversion units are discussed Chemical, solar and nuclear energy sources were considered along with mechanical, thermionic, thermoelectric, photovoltaic, and direct conversion techniques Effects of the external environment encountered by space vehicles are also discussed.

Naval Research Laboratory, Washington, D. C.

304 (NP-11302) DIRECT ENERGY CONVERSION LITERATURE ABSTRACTS. Mildred Benton, comp. (Naval Research Lab., Washington, D. C.). Sept 1961 208p.

A collection of 1044 references from various sources covering the current literature on thermoelectricity, thermionic emission, photoelectric processes, magnetohydrodynamics, electrochemical processes, energy storage, and energy sources is presented. An author index is included.

305 (NP-11455) DIRECT ENERGY CONVERSION LITERATURE ABSTRACTS. (Naval Research Lab., Washington, D. C.). Apr. 1962. 233p.

A bibliography with abstracts covering unclassified literature related to the direct conversion of energy is presented. Subject coverage includes thermoelectricity, thermionic emission, photoelectric processes, magnetohydrodynamics, electrochemical processes, energy storage, and energy sources. The 2825 references are arranged alphabetically by author and various subject headings. An author index is given.

306 (NP-12429) DIRECT ENERGY CONVERSION LITERATURE ABSTRACTS. (Naval Research Lab., Washington, D. C.). Dec. 1962. 121p.

A collection of 735 references from various sources is presented covering the current literature on thermoelectricity, thermionic emission, photoelectric processes, magnetohydrodynamics, electrochemical processes, energy storage, and energy sources.

307 (NP-13277) DIRECT ENERGY CONVERSION LITERATURE ABSTRACTS. (Naval Research Lab., Washington, D. C) July 1963 178p

References and abstracts (1076) to U S. and foreign unclassified literature on thermoelectricity, thermionic emission, photoelectric processes, magnetohydrodynamics, electrochemical processes, energy storage, and energy sources are compiled Availability of the documents is indicated, and an author index is included.

New York Operations Office, AEC, New York, New York

308 (NYO-10689) A BIBLIOGRAPHY ON RADIOISOTOPE POWER SUPPLIES. Daniel M Axelrod and Joseph P. Novarro (New York Operations Office, AEC). Aug 1963 30p.

A bibliography is presented of reports on the research and development and space and terrestrial applications of radioisotope-fueled power supplies.

Oak Ridge National Laboratory, Y-12 Area, Oak Ridge, Tennessee

309 (ORNL-3360(p.102-4)) SHIELDING RESEARCH FOR NUCLEAR SPACE POWER PLANTS C E. Clifford (Oak Ridge National Lab , Tenn)

Shielding research in direct support of the Space Nuclear Auxiliary Power (SNAP) program wherein reactors are utilized as the power source for space vehicles was initiated It includes studies of neutron penetration through LiH and investigations of structure scattering of radiation, both aimed at assisting in the development of an efficient technique for shaping shadow shields on space vehicles

Republic Aviation Corporation, Missile Systems Division, Mineola, New York

310 (NP-12492) A SHORT REVIEW OF SPACE POWER SYSTEM TECHNOLOGY (Republic Aviation Corp Missile Systems Div , Mineola, N Y) May 18, 1962 42p

A brief review is presented of various power systems currently available for space vehicles The systems discussed are solar cells, primary batteries, secondary batteries, fuel cells, solar thermionic systems, nuclear power systems, chemical systems, and microwave power transmission The pertinent characteristics of the available power systems for space application are summarized and compared with each other for specific power levels and missions

Rocketdyne Division, North American Aviation, Inc., Canoga Park, California

311 (AD-282977) INVESTIGATION OF A LINED-CAVITY DESTRUCT CHARGE CONCEPT Final Report E E Lockwood (Rocketdyne Div , North American Aviation, Inc , Canoga Park, Calif) Aug 6 1962 47p (R-3731)

A brief literature survey and experimental program was conducted to demonstrate the feasibility of utilizing a lined-cavity explosive destruct charge (shaped charge) concept for the airborne Small Nuclear Auxiliary Power (SNAP) reactor Linear shaped-charge penetration tests were conducted against 1-in -thick steel witness plate to optimize the charge configuration A circular (continuous ring) shaped charge was then constructed and tested against a reactor mockup vessel Satisfactory demonstration of the ring charge concept was achieved The optimum charge configuration contained a linear explosive loading of 0 5 lb/ft

Royal Research Corporation, Hayward, California

312 (TID-17004) THE CESIUM-137 POWER PROGRAM Quarterly Report No 3 (Royal Research Corp , Hayward, Calif) Oct 31, 1961. Contract AT(04-3)-366 100p. (RRC-0102)

Progress made in the development of the Cs^{137} fueled thermoelectric generator for marine power applications is reported. Information is given on thermoelectric generator design, shielding, power conversion system, hazards evaluation, fuel element forming and cladding, fabrication, and heat transfer Cs^{137} energy calculations are presented along with shielding calculations The development and fabrication of cesium polyglass for fuel application are included

Space Nuclear Propulsion Office, AEC / NASA.

313 (TID-18558) NUCLEAR PROPULSION—AN EMERGING TECHNOLOGY Harold B Finger (Space Nuclear Propulsion Office, AEC/NASA) [1963] 36p

The use of nuclear energy in the space programs is discussed Nuclear rocket development is reviewed, and the Nevada rocket development station, nuclear electric propulsion and power generation, and advanced research projects are discussed

United States Congress, Joint Committee on Atomic Energy, Washington, D. C.

314 HEARINGS BEFORE THE SUBCOMMITTEE ON RESEARCH AND DEVELOPMENT OF THE JOINT COMMITTEE ON ATOMIC ENERGY, CONGRESS OF THE UNITED STATES, EIGHTY-SIXTH CONGRESS, SECOND SESSION ON FRONTIERS IN ATOMIC ENERGY RESEARCH, MARCH 22, 23, 24, AND 25, 1960 (United States Congress Joint Committee on Atomic Energy) 386p

Aspects of Plowshare Project were reported, including research developments, chemical and isotope production, mineral recovery (tar sands, oil shales, and mining uses), energy production and recovery (e g , controlled release of energy from salt melted during nuclear explosion), and excavation uses of atomic explosions The purposes and types of machines used in Sherwood Project were reviewed, and developments at Los Alamos, UCRL, Oak Ridge, and Princeton were examined Advantages of nuclear energy over conventional energy were listed, i e , economy in mining of the fuel, compactness of the fuel, waste controllability, sharp and controllable energy output pulses, ionization, breeding, high temperatures, and research Reactor applications for chemical production and coal studies were described The Rover and Orion Projects were reviewed, and advances in SNAP power sources were noted Direct conversion concepts and programs, including thermionic, photoelectric, and thermoelectric cells were described Uses of these devices for solar energy applications in industry, in the United States and in underdeveloped countries, were suggested

315 HEARINGS BEFORE THE SUBCOMMITTEE ON RESEARCH, DEVELOPMENT, AND RADIATION OF THE JOINT COMMITTEE ON ATOMIC ENERGY, CONGRESS OF THE UNITED STATES EIGHTY-SEVENTH CONGRESS FIRST SESSION ON NUCLEAR ENERGY FOR SPACE PROPULSION AND AUXILIARY POWER AUGUST 28 AND 29 1961 (United States Congress Joint Committee on Atomic Energy) 320p (GPO)

The public hearings cover the progress being made in the development of nuclear rockets and other atomic energy devices for use in space The hearings cover the developments in the joint AEC-NASA nuclear rocket program (Project Rover) the development of long lived nuclear power supplies (SNAP program), and the development of a nuclear ramjet engine to power missiles traveling in the atmosphere (Project Pluto)

316 SPACE NUCLEAR POWER APPLICATIONS HEARINGS BEFORE THE SUBCOMMITTEE ON RESEARCH, DEVELOPMENT, AND RADIATION OF THE JOINT COMMITTEE ON ATOMIC ENERGY, CONGRESS OF THE UNITED STATES, EIGHTY-SEVENTH CONGRESS, SECOND SESSION, SEPTEMBER 13, 14, AND 19, 1962 (United States Congress Joint Committee on Atomic Energy) 376p $1 00(GPO)

Hearings were held before the Subcommittee on Research, Development, and Radiation of the Joint Committee on Atomic Energy of the Congress of the United States on space nuclear power applications Topics discussed included general aspects of the development and use of nuclear energy for space propulsion and power, program plans for carrying out unified development efforts on the various space projects, the Rover nuclear rocket development program, and the SNAP program for the development of compact long-lived electrical power generators for use in space missions, and the Pluto project aimed at the development of a nuclear ramjet engine for powering multimach numbered atmospheric missiles Test results and development plans were also discussed

Miscellaneous

317 AEROSPACE NUCLEAR POWER SAFETY CONSIDERATIONS Joseph A Connor, Jr (U S A F (MC)) Aero/Space Eng , 20: No 5, 26-7; 58-61(May 1961)

Safety considerations in uses of nuclear power plants in space missions are detailed The biological effects, probable amounts, dispersions, and locations of released radioactivity are considered Engineering problems examined include personnel protection, site and range selections, and launching, pre-orbital, and random re-entry failures of vehicles Aspects of manned nuclear aircraft, the Pluto nuclear ramjet, SNAP and Rover unit, and nuclear rocket safety are discussed

318 NUCLEAR ENERGY AND SPACE PROBLEMS. Georges Fleury. Énergie nucleaire, 4 78-84(Mar -Apr 1962) (In French)

The development of space missions depends on the realization of concentrated energy sources for propulsion and on-board power supplies. Nuclear sources have characteristics amenable to these needs. The problems posed and the solutions worked out in the United States are reviewed, viz. SNAP, Rover, and Kiwi. Particular attention is given to the SNAP systems, which utilize either a light fission reactor or radioelements, and which can be of two types· direct propulsion nuclear reactors, or reactors for the production of electrical energy (furnishing propulsion or high power on board).

319
THE SNAP PROGRAMME U S AEC'S SPACE-ELECTRIC POWER PROGRAMME Guveren M Anderson and Frank H Featherston Nuclear Eng 5, 460-3(1960) Oct

Project SNAP, the program for developing electric-power-generating systems for space craft using radioisotope and fission reactor heat sources, is reviewed SNAP-1 is used to designate the program for the development of a radioisotope-fueled space auxiliary power unit using Ce^{144} This turbogenerator was developed and under testing operated in excess of specifications SNAP-3, a program to develop advanced thermoelectric and thermionic conversion devices that could be used with radioisotope heat sources, resulted in a thermoelectric generator using Po^{210} fuel capsules The SNAP-2 system uses a 50-kw(t) compact-core reactor employing liquid NaK as the coolant to transfer heat to a mercury loop to produce 3 kw in a high-speed-shaft unit The complete system weighs approximately 600 lb and is designed for programed start-up in orbit Two additional space power units (SNAP-8 and SNAP-10) were started, based on the metal hydride reactor technology of SNAP-2

320 NUCLEAR ENERGY IN SPACE Nucleonics, 19 No 4, 53-100(Apr 1961)

High- and low-thrust missions and those requiring high auxiliary power levels are discussed Strategies of design and operation for reducing danger to populations are also considered Radionuclide SNAP units provide durable, continuous electric power sources from 1 to 100 w with predictable lifetimes Uses of SNAP units are discussed KIWI-B ground tests with flight configurations are described Problems of high-temperature reactor fuels and engine control during quick startup are investigated Environmental problems of spacecraft, including particle bombardment, heat flux variations and ultra-high-vacuum materials problems are detailed Uses of gaseous- and solid-fuel reactors, along with methods for separating propellants and fuels, and the use of atomic explosion propulsion are described

321 NUCLEAR SPACE PROJECTS FACE UP TO SAFETY PROBLEMS. Harold L. Davis, ed Nucleonics, 21: No. 12, 41-5(Dec 1963)

Some safety aspects of the use of nuclear space power are discussed The SNAP and Rover projects are discussed in terms of disposal of radioactive materials (both intended and accidental) The further complication of nuclear systems by added safeguards is discussed

322 AEROSPACE NUCLEAR SAFETY PROGRAM W K Kern and G B Connor p 25-8 of "Nuclear Safety Vol 4, No 3 "

A program is being conducted on the safety of the operation of reactors and radioisotopic thermoelectric generators, particularly SNAP devices, in space The possible aerospace environments to which the devices might be subjected are outlined, and the scope of the program is described The ground environment studies, flight tests, and excursion tests are discussed

323 SPACE POWER SYSTEMS Nathan W Snyder, ed A Selection of Technical Papers based mainly on A Symposium of the American Rocket Society held at Santa Monica, California September 27-30, 1960 Progress in Astronautics and Rocketry Volume 4 New York, Academic Press, 1961 647p

Thirty-three papers selected chiefly from A Symposium of the American Rocket Society are presented The aspects of solar power systems including the work performed for USA space vehicles are discussed The SNAP program, chemical systems, and space power requirements are also outlined Five papers are covered by separate abstracts Fourteen were previously abstracted for NSA

324 NUCLEAR FRONTIERS—1960 A FORUM REPORT (No 32) Proceedings of the Annual Conference for Members and Guests, San Francisco, California, December 14-16, 1960 Edwin A Wiggin, ed New York, Atomic Industrial Forum, Inc 1961 336p $10.00

Forty six papers are included. Nuclear aspects of space exploration are described, including government contracting policies and industry participation, SNAP program, Rover program, space safety, management and objectives, and social implications Uranium production, processing, and forecasted needs are discussed The present and future status of IAEA is outlined, legal problems are examined in international atomic energy contracts, such as roles of the U S and foreign governments in these contracts, and vehicles for transacting the contracts abroad Foreign nuclear development programs (Indatom, OEEC, Euratom, and Belgian, French, and Japanese programs) are outlined The cooperation necessary between federal and state governments in domestic atomic energy activities is discussed The AEC's effects on industry, including reactor licensing procedures, patent rights of contractors, promotional and regulatory functions, and government supports, are reviewed Problems involved in gaining public acceptance and understanding of atomic activities are described Problems involved in initiating a power reactor project are studied, these problems include siting, safety, official approval, and private utility aspects Economic aspects, reprocessing and transportation methods, and selection of fuel clad and matrix materials for reactor fuels are discussed The Texas program, pulsed reactors, direct conversion methods, and fissio-chemical reactor potentials are analyzed, new radiation and radioisotope applications are discussed

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6476	213	Dep.(mc); $5.60(fs), $1.91(mf)OTS
7036	181	Dep.; $0.50(OTS)
7085	214	Dep.(mc); $3.60(fs), $1.40(mf)OTS
7140	97	Dep.; $1.25(OTS)
7288	182	Dep.; $1.00(OTS)
7293	160	Dep.; $0.75(OTS)
7368	215	Dep.; $0.75(OTS)
7408	216	Dep.(mc); $10.10(fs), $3.92(mf)OTS
7432	217	Dep.; $0.75(OTS)
7786	218	Dep.; $1.00(OTS)
7797	98	Dep.; $1.25(OTS)
8097	99	Dep.; $1.00(OTS)
8127	161	Dep.; $0.75(OTS)
8303	100	Dep.; $1.75(OTS)
8304	183	Dep.; $0.75(OTS)
8468	162	Dep.; $0.75(OTS)
8490	123	Dep.; $1.00(OTS)
NAA-SR-Memo		
4796	101	Dep.(mc); $1.60(fs), $0.80(mf)OTS
4910	102	Dep.(mc); $1.10(fs), $0.80(mf)OTS
5004	103	Dep.(mc); $4.80(ph), $2.70(mf)OTS
5166	104	Dep.(mc); $3.30(ph), $2.40(mf)OTS
5302	105	Dep.(mc); $7.80(ph), $3.30(mf)OTS
5423	106	Dep.(mc); $1.80(ph), $1.80(mf)OTS
5433	107	Dep.(mc); $3.30(ph), $2.40(mf)OTS
5716	108	Dep.(mc); $1.80(ph), $1.80(mf)OTS
5772	219	$6.30(ph), $3.00(mf)OTS
5952	109	Dep.(mc); $1.60(fs), $0.80(mf)OTS

Report No.	Reference	Availability
NAA-SR-Memo (cont'd)		
5961	110	Dep.(mc); $1.60(fs), $0.80(mf)OTS
5974	184	Dep.(mc); $1.60(fs), $0.80(mf)OTS
5982	111	Dep.(mc); $1.60(fs), $0.80(mf)OTS
6408	112	Dep.(mc); $2.60(fs), $0.83(mf)OTS
6515	185	Dep.(mc); $1.10(fs), $0.80(mf)OTS
6531	113	Dep.(mc); $3.60(fs), $1.19(mf)OTS
6662	114	Dep.(mc); $2.60(fs), $0.98(mf)OTS
6670	186	Dep.(mc); $1.60(fs), $0.80(mf)OTS
6921	187	Dep.(mc); $1.10(fs), $0.80(mf)OTS
7456	153	Dep.(mc); $2.60(fs), $0.83(mf)OTS
7527	115	Dep.(mc); $1.10(fs), $0.80(mf)OTS
7573	116	Dep.(mc); $4.60(fs), $1.70(mf)OTS
7594	220	Dep.(mc); $1.10(fs), $0.80(mf)OTS
7789	117	Dep.(mc); $1.60(fs), $0.80(mf)OTS
7945	118	Dep.(mc); $1.60(fs), $0.80(mf)OTS
8074	188	Dep.(mc); $2.60(fs), $0.89(mf)OTS
8145	189	Dep.(mc); $3.60(fs), $1.13(mf)OTS
8268	190	Dep.(mc); $1.60(fs), $0.80(mf)OTS
8440	221	Dep.(mc); $3.60(fs), $1.22(mf)OTS
8675	163	Dep.(mc); $1.60(fs), $0.80(mf)OTS
8817	164	Dep.(mc); $3.60(fs), $1.19(mf)OTS
8824	191	Dep.(mc); $3.60(fs), $1.13(mf)OTS
9043	119	Dep.(mc); $9.10(fs), $3.38(mf)OTS
9088	192	Dep.(mc); $1.60(fs), $0.80(mf)OTS
9101	222	Dep.(mc); $6.60(fs), $2.21(mf)OTS
NASA-TN-D		
769		Dep.(mc); $2.50(OTS)
769(p.33-44)	120	
769(p.57-9)	159	
1188	169	$3.00(OTS)
1529	173	$0.50(OTS)
NP		
11302	304	$3.50(OTS)
11455	305	$3.50(OTS)
12429	306	$3.50(OTS) as AD-293856
12492	310	
13033	157	
13277	307	$3.00(OTS) as AD-423466
NYO		
10462	58	$3.60(fs), $1.40(mf)OTS
10689	308	Dep.(mc); $2.60(fs), $1.10(mf)OTS
ORNL		
3360		$4.00(OTS)
3360(p.102-4)	309	
PWA		
2043	175	
2088	176	
2255	177	$6.60(fs), $2.03(mf)OTS
2279	178	
RAD-TR		
61-28	236	
SC-DC		
3248	83	Dep.(mc); $1.60(fs), $0.80(mf)OTS
3553		Dep.; $4.50(OTS)
3553(p.65-78)	193	
3553(p.91-102)	50	
SY		
5396-R1	200	
5396-R2	201	$8.60(OTS
5396-R3	202	
5396-R4	203	
5396-R5	204	$3.60(OTS) as AD-414876
5396-R6	205	
TID		
3561(Rev. 3)	238	Dep.; $1.50(OTS)
6312	223	Dep.; $1.25(OTS)

Report No.	Reference	Availability
TID (cont'd)		
6612	207	Dep.(mc); $6.30(ph), $3.00(mf)OTS
6814	148	Dep.(mc); $7.60(fs), $2.57(mf)OTS
6815	149	Dep.(mc); $10.80(ph), $3.90(mf)OTS
7571		Dep.; $2.75(OTS)
7571(p.27-38)	51	
7599		Dep.; $5.75(OTS)
7599(p.263-76)	121	
7626(Pt. I)		Dep.; $2.75(OTS)
7626(p.87-91)	122	
11307	150	Dep.(mc); $11.00(fs), $4.49(mf)OTS
13905	158	Dep.(mc); $1.60(fs), $0.80(mf)OTS
17004	312	Dep.(mc); $8.60(fs), $3.20(mf)OTS
17306	138	Dep.(mc); $8.60(fs), $3.14(mf)OTS
18028	243	Dep.(mc); $11.50(fs), $4.91(mf)OTS
18323	284	Dep.(mc); $10.50(fs), $4.19(mf)OTS
18558	313	Dep.(mc); $3.60(fs), $1.28(mf)OTS
18754	208	IAEA Preprint No. CN-14/41. To be published in proceedings of Conference on the Application of Large Radiation Sources in Industry, held in Salzburg, Austria, May 27-31, 1963
18761	77	IAEA Preprint No. CN-14/22. To be published in proceedings of Conference on the Application of Large Radiation Sources in Industry, Salzburg, Austria, May 27-31, 1963
18880		See NAA-SR-8490
19458	154	Dep.(mc); $1.60(fs), $0.80(mf)OTS
19563	155	Dep.(mc); $3.60(fs), $1.16(mf)OTS
20046	156	Dep.(mc); $3.60(fs), $1.16(mf)OTS
WADD-TR		
60-699(Vol. XI)	285	OTS