181

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FORM OF DOCUMENT	CORRESPONDENTS OR TITLE		DATE	RESTRICTION
~~#1 memo~~	~~to McG. Bundy, George Reedy, Donald Hornig,, et from E. C. Welsh confidential~~ open 6-23-03 NLJ02-117	1 p	04/23/64	A
~~#2 memo~~	~~to George Reedy & McG. Bundy from E. C. Welsh confidential~~ open 3/14/02	~~1 p~~	~~04/16/64~~	~~A~~
~~#10 memo~~	~~to President from E. C. Welsh~~ open 3/14/02 ~~confidential~~	~~1 p~~	~~02/25/64~~	~~A~~
~~#10a memo~~	~~to Preisdent from E. C. @3lsh~~ Welsh open 3/14/02 ~~confidential~~	~~1 p~~	~~02/25/64~~	~~A~~
~~#15 memo~~	~~to Bromley Smith from David Klein~~ open 3/14/02 ~~confidential~~	~~2 p~~	~~01/31/64~~	~~A~~
~~#16-b report~~	~~re: response to queries~~ open 3/14/02 ~~confidential~~	~~1 p~~	~~01/27/64~~	~~A~~
~~#17b cable~~	~~Geneva 1503~~ top secret open 8-16-08	1 p	01/24/64	A
~~#21 memo~~	~~to President from E. C. Welsh~~ open 3/14/02 ~~confidential~~	~~1 p~~	~~12/03/63~~	~~A~~
~~#25 report~~	~~Special Space Review draft report~~ open 3/14/02 ~~secret~~	~~25 p~~	~~11/29/63~~	~~A~~
~~#26 report~~	~~Special Space Review draft report~~ open 3/14/02 ~~secret~~	~~25 p~~	~~11/29/63~~	~~A~~
#29 cable	~~#1831 from USUN NY~~ confidential open 4-16-09	3 p	11/05/63	A
~~#33 report~~	~~re: Outer Space in the 1970's~~ open per NLJ 02-122 8/7/02 ~~secret (gp 2)~~	~~87 p~~	~~01/30/64~~	~~A~~

FILE LOCATION

NATIONAL SECURITY FILE, Subject File
Space, Outer vol. I
Box 37

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~~CONFIDENTIAL~~

Space
~~L. G. Johnson~~
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EXECUTIVE OFFICE OF THE PRESIDENT
NATIONAL AERONAUTICS and SPACE COUNCIL
WASHINGTON

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EXECUTIVE SECRETARY April 23, 1964

DECLASSIFIED
E.O. 12958, Sec. 3.6
NLJ 02-117
By ~~ics~~, NARA, Date 6-17-03

MEMORANDUM to:

Dr. McGeorge Bundy, The White House
Mr. George Reedy, The White House
Dr. Donald Hornig, OST
Mr. Robert Packard, State
Mr. Harold Finger, NASA
Dr. Paul C. Tompkins, FRC

Subject: Launch of SNAP 9-A

This memorandum contains preliminary information regarding subject launch.

The navigation satellite (5 BN-3) powered by a SNAP 9-A radioisotope power source was launched toward a polar orbit by a THOR-ABLESTAR vehicle from the Pacific Missile Range on April 21. The payload did not attain orbit.

There was an apparent malfunction of the command guidance system accompanied by a short first burn of the ABLESTAR. The doppler tracking station at Pretoria, South Africa, acquired the payload east of Africa, moving north. Late acquisition, steep doppler shift, and sudden termination of the signal all indicate that the payload reentered the atmosphere over the South Indian Ocean. Tracking stations in England and Alaska did not acquire the satellite. NORAD confirms that it is not in orbit.

It is considered most likely that the plutonium fuel in the generator was dispersed as small particles at high altitudes during burnup on reentry.

DOD and AEC and their contractors are currently analyzing all vehicle and payload performance data to provide a more complete evaluation of the flight. An attempt to determine the precise impact point is being made.

The attached proposed press release is currently being cleared through AEC and DOD. It would be best if all public inquiries on this incident were directed to these agencies.

E. C. Welsh

~~CONFIDENTIAL~~

Attch: Proposed Press Release

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April 22, 1964

Preliminary data indicate that the satellite launched yesterday from Vandenberg Air Force Base California by an Air Force THOR ABLE STAR space booster did not achieve orbit and probably burned up upon re-entry into the earth's atmosphere. The satellite carried a small SNAP-9A atomic generator as the power supply for auxiliary equipment.

From previous safety analysis and tests it had been concluded the re-entry will cause the plutonium 238 fuel to burn up into particles of about one-millionth of an inch in diameter. These particles will be widely dispersed and diluted in the upper atmosphere and would not constitute a health hazard.

Two of these SNAP-9A generators have been successfully orbited and operated in space since September, 1963. The small light weight thermoelectric device is approximately 20" in diameter, 10" high, weighs 27 pounds and has no moving parts. Since it requires no battery storage system and can provide 20 watts of power for an extended period, it is expected to have a variety of applications in satellites.

1731

~~CONFIDENTIAL~~

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EXECUTIVE OFFICE OF THE PRESIDENT
NATIONAL AERONAUTICS and SPACE COUNCIL
WASHINGTON

Space

EXECUTIVE SECRETARY

April 16, 1964

MEMORANDUM FOR:

Mr. George Reedy
Mr. McGeorge Bundy

Subject: Rescheduled Launch of SNAP Device in Navigation Satellite

My memorandum for the President of March 25 advised of plans for the launching of the last in a series of three radio-isotope powered navigation satellites. This launch was later postponed, and is now scheduled for April 21.

DOD and AEC will handle the publicity for this launch in a routine manner.

E. C. Welsh

~~CONFIDENTIAL~~

Space
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April 14, 1964

MEMORANDUM FOR

GENERAL CLIFTON

Following is a report from NASA on the accident at the Cape:

Inadvertant ignition of the third stage, solid fuel engine during mating of the OSOB resulted in an accident which seriously injured at least eight persons, one of which was critical. It of course damaged the vehicle and greatly damaged the spin-table of the spacecraft spin test facilities at the Cape. So, of course, besides the damage to the Bird, the flight is postponed indefinitely.

The injury to the eight people and the damage to the vehicle is going to have some impact on other launches which would employ the Thor vehicle, and that is the only one we have down there. So that is going to pass some doubt on SYNCON and other flights which employ the IMP program, for example, later on this year -- this is speculation, but I am afraid it is real good speculation -- and the EPE, the Energetic Particle Explorer, all of which employ the same booster vehicle so all of the scheduled flights will be affected until repairs are made to it.

Art McCafferty

cc: Bromley Smith

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Space

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OUTGOING TELEGRAM Department of State

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ACTION: Amembassy ALGIERS 1963
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Apr 2 6 05 PM '64

EMBTEL 1975

French/US Dragon experiment involves launching U.S. scientific payload and/French sounding rocket Dragon. This is cooperative space program between French CNET and U.S. NASA. Archer and two other NASA technicians due to be in Algiers at Hammaguir until after launching which may occur any time between April 10 and 12. Program is unclassified, scientific and results will be made available to World Scientific Community. Full details this cooperative program will be pouched.

Embassy Paris requested to determine whether GOF has informed GOA of our role in experiment and, if not, to state our wish that this be done. Suggest Embassy Algiers coordinate any responses to outside queries re experiment with French Embassy.

END

RUSK

SS

Drafted by: SCI:CEDillery:4/2/64:lls

Telegraphic transmission and classification approved by: SCI - T. H. E. Nesbitt

Clearances: NASA - Mr. Bivins (subs) AFN - Mr. Stoltzfus

LIMITED OFFICIAL USE

FORM 8-63 DS-322

Washington Post - April 4, 1964

Space

5

U.S. Rocket Deception Sows Radar Confusion

CAPE KENNEDY, Fla., April 3 (AP)—A Minuteman missile thundered from an underground launching silo here recently and streaked toward a target in the South Atlantic Ocean 5000 miles away.

As the warhead sped along, radar, infrared and electronic tracking gear on ships, planes and Ascension Island zeroed in on the vehicle. Suddenly, the detection systems were flooded with blips and flame patterns that obscured the warhead.

As the missile began its plunge back to earth, it had unleashed several rocket-powered dummy warheads designed to confuse the trackers.

Earlier that day, an Atlas hurled a new, slender nose cone over the same course. The purpose of the pointed cone, which carried a control system to keep it nose down, was to reduce its radar image.

Confusion Is Object

If the radar cross-section is small enough, signal returns to the tracking radar may be absorbed in the receiver, or returns may be so imperceptible that they would be confused with those from dummy warheads.

The Atlas also conducted the first of a series of tests to develop decoys that will emit the same infrared and other visible spectrum wave lengths created by the real warhead when it slams into the heat barrier of the atmosphere.

The two launchings, last Feb. 25, underscored the United States program to develop effective warhead penetration aids (Penaids) intended to confuse enemy detection equipment in case of war.

The United States this year is expected to spend more than $300 million on development of various Penaid systems.

The rocket-powered decoys fired for the first time by a Minuteman use their individual propulsion systems to accelerate to the same speed as the warhead or to spurt ahead to spread chaff in front for additional deception.

Other Methods Tested

Penaid experts also are testing these methods to upset radar:

- When radar has locked on a warhead, fire a small rocket attached to it to suddenly shoot it off the screen. The few moments of confusion would let the fast-moving warhead get through.
- Nose cone coating materials to absorb radar pulses, preventing them from bouncing back to earth.
- Electromagnetic countermeasures, either in decoys or the warhead, to jam radar and other tracking devices.
- Inflate a huge metallic balloon on the tip of the nose cone to give radar a clear picture. The balloon would burn up on reentry and the radar image would be swiftly reduced to a pinpoint with resulting confusion.

Before long, Air Force missiles will be experimenting with maneuverable warheads. They will have guidance systems that will permit them to leave their fixed ballistic trajectories and change course to a different target during the terminal dive.

Planners believe the most effective Penaid will be a missile with multiple warheads—two, three or more nuclear packages that would separate and fly to different targets. Decoys would be part of the system, which reportedly is making progress.

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~~CONFIDENTIAL~~

EXECUTIVE OFFICE OF THE PRESIDENT
BUREAU OF THE BUDGET
WASHINGTON 25, D.C.

Dungan 3/17
6

MAR 17 1964

MEMORANDUM FOR THE PRESIDENT

Subject: Designation of Secretary of Defense as Executive Agent to arrange for services from the Communications Satellite Corporation

The attached memorandum from the Deputy Secretary of Defense requests that you designate the Secretary of Defense to arrange for procurement of satellite communications services in his capacity as Executive Agent for the National Communications System.

We have reviewed this proposal from the standpoint of its relation to the National Communications System and recommend that you approve as requested the proposed memorandum (Tab 2) to the recipients of NSAM 252 which established the National Communications System.

The proposed action is consistent with the previously assigned functions of the Secretary of Defense as Executive Agent for the NCS, and is stated by Mr. Vance to be concurred in by the Ad Hoc Group on Satellite Communications of which Mr. Katzenbach and Dr. Hornig are co-chairmen.

We have not reviewed in detail and therefore are not in a position to evaluate the provisions of the proposed Memorandum of Understanding (Tab 1), which has been negotiated by the Secretary of Defense with the Communications Satellite Corporation. The approval we are recommending of the memorandum attached as Tab 2 does not constitute specific Presidential approval of the proposed Memorandum of Understanding.

DECLASSIFIED
Authority Group 4
By alt, NARA, Date 1-23-89

(signed) Kermit Gordon
KERMIT GORDON
Director

Attachments

GROUP 4
DOWNGRADED AT 3-YEAR INTERVALS;
DECLASSIFIED AFTER 12 YEARS

~~CONFIDENTIAL~~

CONFIDENTIAL

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THE SECRETARY OF DEFENSE
WASHINGTON

13 MAR 1964

MEMORANDUM FOR THE PRESIDENT

SUBJECT: Procurement of Satellite Communications Services for the National Communications System from the Communications Satellite Corporation

The discussions under way to explore whether it would be feasible for the Communications Satellite Corporation to provide satellite communications services for the NCS, using the Government's transportable and fixed ground terminals, through the global system the Corporation will deploy have resulted in a Memorandum of Understanding covering these services (Tab 1). The Corporation's Board of Directors and management favor entering into the arrangement. They believe that it must also be acceptable to the communications common carriers and the key European countries interested in investing in the global system. Discussions with these parties and appropriate Congressional Committees are in process.

The terms of the Memorandum are substantially agreed upon. An outstanding question with respect to frequency allocation is still being resolved. The Memorandum makes provision for adequate satellite services to be supplied for the NCS if it should develop that the global system the Corporation decides to deploy is not suitable for the Government's needs.

Inasmuch as the Memorandum of Understanding deals with the satellite circuits required for the entire NCS, it would be preferable that the Memorandum be executed by the Secretary of Defense as Executive Agent for the NCS. This would permit the arrangements for the Government's procurement of such services to be integrated with anticipated arrangements for the participation of other governments in the global system which may result from discussions being carried on with foreign governments by the Corporation and the Department of State. Accordingly, I have prepared for your approval Tab 2 which would authorize the Secretary of Defense, as Executive Agent for the NCS, to sign the Memorandum of Understanding on behalf of the Government. Previous directives are not explicit in giving this power to the Secretary of Defense. The Ad Hoc Committee Group on Satellite Communications concurs in this course of action.

DECLASSIFIED
Authority DOD DIR 5200.1
By DCB, NARA, Date 1-23-89

Signed
CYRUS R. VANCE
DEPUTY

Enclosures 2

DOWNGRADED AT 3 YEAR INTERVALS;
DECLASSIFIED AFTER 12 YEARS.
DOD DIR 5200.10

CONFIDENTIAL

SEC DEF CONT NO. X-1287

March 17, 1964

MEMORANDUM FOR DR. HAROLD BROWN,
DEPARTMENT OF DEFENSE

This is to confirm my telecon request to you for information as to when communication satellites are expected to become operational for military communication purposes, and if the use of such satellites may reduce or eliminate the need for certain communication bases now maintained around the world.

This request is not urgent, and the information can be fitted into your program as your own judgment may advise.

Charles E. Johnson

Information Copies: Mr. Bundy
Mr. Keeny

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Space

EXECUTIVE OFFICE OF THE PRESIDENT

NATIONAL AERONAUTICS and SPACE COUNCIL

WASHINGTON

8

EXECUTIVE SECRETARY March 5, 1964

MEMORANDUM FOR:

Mr. Pierre Salinger
Mr. McGeorge Bundy

Subject: Delay in Launch of Third SNAP 9-A

This refers to my confidential memorandum for the President of February 25. The launch of the radio-isotope powered navigation satellite previously scheduled for this week will be delayed approximately six weeks due to a major failure in the launch vehicle found during check out.

E. C. Welsh

OFFICIAL USE ONLY

9

February 27, 1964

Space

MEMORANDUM FOR MR. BUNDY

Mac --

I hope we can get the President to focus on Jim Webb's report on cooperation with the Soviet's in space before too long. I have had several follow-up inquiries as to the status of the matter and I am afraid that the agencies involved in the preparation of this report will be guessing that there is some problem involved of which they are not aware. If there is anything I can do to help on this, please let me know.

CEJ

Charles E. Johnson

Rec'd 2/26/64

CONFIDENTIAL

Space

27

10

EXECUTIVE OFFICE OF THE PRESIDENT

NATIONAL AERONAUTICS and SPACE COUNCIL

WASHINGTON

EXECUTIVE SECRETARY

February 25, 1964

MEMORANDUM FOR THE PRESIDENT

Subject: Proposed Launch of SNAP Device in Navigation Satellite

The last in a series of three radio-isotope powered navigation satellites is scheduled for launching on March 5. The first two launchings on September 28 and December 5 were entirely successful. This launch will be a repeat performance using the same health and safety criteria.

The Executive Secretary of the Space Council coordinated the arrangements and President Kennedy approved the series of launches prior to the first shot. Unless there is an objection, this launch will proceed on schedule.

All publicity covering this launch will be handled in a routine manner by the Department of Defense and Atomic Energy Commission.

E. C. Welsh

E. C. Welsh

~~CONFIDENTIAL~~

CONFIDENTIAL

Space

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EXECUTIVE OFFICE OF THE PRESIDENT

NATIONAL AERONAUTICS and SPACE COUNCIL

WASHINGTON

EXECUTIVE SECRETARY

February 25, 1964

MEMORANDUM FOR THE PRESIDENT

Subject: Proposed Launch of SNAP Device in Navigation Satellite

The last in a series of three radio-isotope powered navigation satellites is scheduled for launching on March 5. The first two launchings on September 28 and December 5 were entirely successful. This launch will be a repeat performance using the same health and safety criteria.

The Executive Secretary of the Space Council coordinated the arrangements and President Kennedy approved the series of launches prior to the first shot. Unless there is an objection, this launch will proceed on schedule.

All publicity covering this launch will be handled in a routine manner by the Department of Defense and Atomic Energy Commission.

E. C. Welsh

cc: Mr. Bundy

CONFIDENTIAL

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AEC

UNITED STATES
ATOMIC ENERGY COMMISSION
WASHINGTON, D.C. 20545

~~C Johnson~~

FEB 20 1964

Return to McB files

Mr. McGeorge Bundy
Special Assistant to the President
Executive Office of the President

Dear Mr. Bundy:

Enclosed are the Commission's analysis and conclusions on the SNAP program. We believe you will find them informative.

If you have any questions, we shall be glad to answer them.

Sincerely yours,

A.R. Luedecke
General Manager

Enclosures:
As indicated above.

1576

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11a

U. S. ATOMIC ENERGY COMMISSION

HOLD FOR RELEASE
UNTIL 10:00 AM EST
THURSDAY, FEBRUARY 20

Attached are pre-release copies of the following reports:

1. SNAP...a Report by the Commission--1964;

2. SNAP...an Evaluation--January 1964.

This material is embargoed for use by news media after 10:00 AM, EST, Thursday, February 20.

Attachments:
As stated above

1576

1064

11-b

Systems for Nuclear Auxiliary Power

... a Report by the Commission - 1964

U.S. ATOMIC ENERGY COMMISSION

1576

SYSTEMS FOR NUCLEAR AUXILIARY POWER

A Report by the Commission - 1964

U. S. ATOMIC ENERGY COMMISSION

February 1964

TABLE OF CONTENTS

PREFACE

In space and other inaccessible and barren regions, many power needs can be satisfied best with nuclear systems; large amounts of power often must be nuclear. With the advent of a vigorous space program, such applications for nuclear energy became increasingly practical and interesting. Under the Atomic Energy Act, the Commission is charged with developing the use of atomic energy. In line with this responsibility, a comprehensive program is being carried out to make available complete systems for nuclear auxiliary power (SNAP). To date, four small devices powered by radioisotopes have been put in operation in space orbit; two much larger fission-powered space reactors have been ground tested; five radioisotopic power units for terrestrial weather and navigational uses are in operation.

Late in 1962 the Commission began a special study of the efforts to develop reactors for auxiliary power in space and radioisotopic sources for space and terrestrial applications. Discussions were held with other government agencies and major industrial and national laboratory organizations interested in the development and use of auxiliary nuclear power in space. Increased attention was given to all Commission activities related to the SNAP program. The Office of Program Evaluation in the Division of Reactor Development was assigned responsibility for preparing an evaluation of the SNAP program. Their evaluation of the SNAP program as of January 1964 is being published separately and serves as backup information to this report by the Commission.

A 1962 study made by the Commission on the future of civilian nuclear power was able to predict future demand for power using past experience with the national demand for electricity. Prediction of the magnitude of the need for space power cannot be helped by any such past experience. The SNAP study has shown that without DOD and NASA firm mission requirements for nuclear power, one must estimate in his own best judgment the various power needs for the missions that appear to be possible and desirable in the future.

As the SNAP study developed, it became apparent that space rather than terrestrial applications required the major attention. Terrestrial applications of isotopic systems have been made and will continue to be made; increased utilization of such systems will result principally from improved economics, e.g. lower costs for radioisotopes, which will be achieved in part through the planned program for large-scale utilization of radioisotopes from Hanford wastes. Therefore, this report is directed more toward space applications including the relatively extensive effort to develop space reactor systems.

The Commission has drawn several conclusions which are as follows:

1. Nuclear auxiliary power offers unique advantages to a wide variety of space missions. The SNAP development program should be concentrated on approaches to provide these advantages, which include among others, light weight, compact fission and radioisotopic systems in a power range up to 20 KWE, and reactor systems with long life at higher power.
2. The performance of ambitious space missions will require amounts of reliable power so large that they can be achieved only from nuclear systems. Continued timely development of advanced SNAP technology is necessary to meet this need.
3. In the absence of near term specific mission requirements, the SNAP reactor technology must be developed to meet power requirements within several power ranges (kilowatts, tens of kilowatts, and hundreds to thousands of kilowatts) thereby making available a technological base for the specific systems for ultimate mission use.
4. Development of SNAP technology should be carried forward with the Commission giving full attention to the integration of the converter with the nuclear heat source.

5. Where Commission responsibility for power system developments involve first-of-a-kind technology and equipment, the program should extend through the demonstration phase, including ground and flight testing as necessary, and should encompass programs for the resolution of safety problems.

6. The orderly development of SNAP technology through the demonstration phase should provide users with information and experience needed for them to specify and obtain nuclear power systems and to assist in planning their missions.

This SNAP Report presents the AEC program for the development of technology and systems for nuclear auxiliary power which, in the judgment of the Commission, will meet in an orderly manner the near and far term requirements of the national space effort.

There are substantial development efforts in NASA and DOD on non-nuclear auxiliary power systems. Occasionally the same components can be used with either a nuclear or a non-nuclear heat source. Commission programs are coordinated with such efforts.

The close cooperation and assistance provided by the National Aeronautics and Space Administration, the Department of Defense, and various industrial firms and other organizations engaged in or interested in the nuclear space program facilitated the preparation of the report and are gratefully acknowledged.

Former Commissioner Robert E. Wilson was an active participant with us in the preparation of this report.

UNITED STATES ATOMIC ENERGY COMMISSION

Gerald F. Tape

John G. Palfrey

James T. Ramey

Glenn T. Seaborg, Chairman

February 17, 1964

INTRODUCTION

Man, as he moves into the space age, will encounter many unique and difficult problems, not the least of which will be his ability to produce the power necessary to accomplish his ambitious objectives.

The energy that can be obtained from the atomic nucleus is an advantageous and even vitally needed source of space power. The responsibility of the Commission in such a situation was clearly stated by Congress. The policy of the United States is that development, use, and control of nuclear energy shall be directed by the Commission so as to make the maximum contribution to the general welfare, subject at all times to the paramount objective of making the maximum contribution to the common defense and security; it is the stated purpose of the Atomic Energy Program to provide for conducting, assisting, and fostering research and development in order to encourage maximum scientific and industrial progress.

The Atomic Energy Commission is unique among Executive Branch departments and agencies in having for its major purpose the development of as specific a field as nuclear energy. Other agencies of the Executive Branch have broadly defined scientific, technical, and operational responsibilities for contributing to the general welfare and security of the nation. Having a more specific responsibility, the Commission does not retain sole authority and responsibility over nuclear applications as developmental projects approach completion and as nuclear devices start to meet specific power requirements and thus enter the mainstreams of national activity. To an increasing extent the authority then spreads to others; thus successful developments in nuclear auxiliary power for space will be followed by repetitive DOD and NASA procurement of the demonstrated systems. At such times the continuing interests of the Commission emphasize assuring the continued safety of the general public and the availability of supplies of fuel adequate for users' needs.

In keeping with its responsibilities under the Act, the Atomic Energy Commission has engaged in vigorous development and demonstration of nuclear power systems for space missions of established or possible interest to the National Aeronautics and Space Agency (NASA) and the Department of Defense (DOD). The total effort, which also involves participation by other agencies, includes development of rockets that use nuclear reactors to provide heat energy to propellant gas and of systems for nuclear auxiliary power. The latter, called SNAP systems*, can provide electric power for such uses as operating sensing devices, transmitting and receiving radio, radar, telephone and television signals, providing the heat and electrical power needed to support astronauts for long periods of time, and ultimately providing the means to propel rockets to greater distances at higher speeds by electrical acceleration of the rocket exhaust.

* For a tabulation of SNAP systems, see Tables 1 and 2 on pages 39 and 40.

All SNAP units generate heat energy part of which can be used to make electricity. Radioisotopic SNAP units stay at a high temperature for years due to a slow process of spontaneous radioactive change going on within the units. Electrical circuits of thermoelectric materials, when placed tightly against the hot outer surface of the radioisotope containers, generate a flow of electricity between hot and cold parts of the circuit. This electricity is used to operate the payload. Reactor SNAP units obtain their energy from neutron-induced fission of uranium. SNAP reactors differ from other reactors primarily in their compactness: typical reactor cores are contained in vessels about the size of a five gallon can. Reactor heat is transported by a fluid coolant from the core to equipment for converting heat to electrical energy.

Terrestrial applications of isotopic SNAP systems and technology are to be expected and have been made. These devices have demonstrated their unique advantages for use in rigorous environments and in barren, inaccessible places. Automatic weather stations in polar regions and at sea, navigational signals, and ocean-bottom beacons have been developed and are being demonstrated in the terrestrial SNAP program.

The program to develop SNAP systems includes research and the engineering development needed for proof of technical feasibility and safety of the more promising types of systems, as well as project-oriented efforts to demonstrate the practical feasibility and utility of specific systems. The program has taken full advantage of the extensive useful information and the experienced scientists and engineers available from other established military and civilian programs. It has achieved notable success in developing small systems powered by radioisotopes. The program to develop and demonstrate larger systems powered by nuclear reactors is well under way, but will require much more time and effort and more extensive facilities than the earlier efforts on smaller systems.

In order to consider the magnitude and timing of the need for systems for nuclear auxiliary power, especially in meeting present and future space power demands, this report first considers the magnitude, characteristics, and likelihood of occurrence of uses for all auxiliary power systems, and then discusses the extent to which nuclear, or other, power systems can meet them. This report also considers the programs under way and planned for the future, and finally presents the Commission's conclusions on the over-all SNAP program.

USES FOR AUXILIARY POWER

Meaningful consideration of uses for auxiliary power in relationship to the effort to provide actual auxiliary power systems must include an estimate of the sequence of missions and their time scale. However, it is difficult to predict the character of space programs of the more distant future. Until the timing of missions after 1970 is better defined, and until the needs of the manned lunar landing program have been met, the national space effort probably will not undertake new major programs. This leads to the conclusion that many of the more ambitious space programs - programs which will generate the major space power requirements of the future - will not make their needs felt until at least the seventies. After that time, it is probable that power requirements will continue to expand in magnitude and complexity.

The presently stated requirements for power in space - those that are a part of an agency's approved program - are not comprehensive enough for use in a meaningful detained analysis of the role of nuclear energy in space. The potential requirements for auxiliary power systems to be used in missions that appear reasonable for the future indicate a major role for nuclear energy.* This potentially large number of uses for auxiliary power systems must be considered seriously. While some of the missions that currently seem reasonable probably will prove not to be so, some additional missions as yet unconceived will actually be carried out.

*For further information the reader is referred to the Evaluation Report, Tables 1 and 7 of "An Evaluation of Systems for Nuclear Auxiliary Power," a January, 1964 report by the Commission staff (TID-20079).

Low power systems for which radioisotopic SNAP units might be employed are needed for contemplated missions covering all regions of space - earth, lunar and planetary orbiting and lunar and planetary probes. Low power systems would be used on scientific satellites in probes used to explore lunar and planetary environments and surfaces; in long-lived satellites used to observe terrestrial weather conditions; and for radio navigation transmissions. Some of these applications are for continuing systems that involve periodic replacement of satellites and thus require a number of identical sources. Similar terrestrial applications would be in navigational markers for use by ships and planes and in unmanned weather and seismic stations for use in remote or inaccessible regions of the earth. Ocean-bottom signalling devices include precise mid-ocean navigational aids for use by general shipping, by radar picket and missile tracking ships, and by submarines operating under polar ice. Ocean-bottom and underwater detection systems include surveillance systems for submarines off the coast, missile splash detectors, and seismographic and oceanographic instrumentation.

Currently planned future missions in this lower power range are indicative of the type of demands that are inevitable as the objectives of the over-all space effort begin to take shape. A compilation has recently been made of probable space auxiliary electric needs, regardless of the type of system (e.g., solar cells, radioisotopes, or chemical batteries), for unmanned satellites and probes to be launched during the four years prior to 1968. Missions beyond 1967 are a matter of speculation, but a very rough estimate has been made for systems requiring up to 500 watts of electricity per unit. The results of this compilation and estimate are given below.

Time Period		Aggregate Needs for Space Auxiliary Electric Power (Unit Sizes up to 500 Watts)
1964 to 1967, Inclusive	-	20,000 watts
Beyond 1967	-	In excess of 5,000 watts per year

Terrestrial applications of SNAP devices in this power range may well equal or exceed the above needs for use in space.

Potential requirements for units to produce 500 or more watts have been identified, but the scheduling is too nebulous at this time for similar estimates of aggregate needs. The higher power systems, for which reactor SNAP units might be employed, would be used in earth orbits for large manned space stations, for lunar bases, for manned planetary missions, for more powerful meteorological satellites capable of providing better information on weather conditions, for direct broadcasting of television from stationary overhead satellites to individual sets in entire nations, and for large-scale intercontinental telephone service. This report does not include full consideration of possible military uses for SNAP systems; however, such consideration would include use of military systems in earth orbit for reconnaissance and surveillance missions, communications, and manned orbiting systems.

When there is a need for travel to greater distances from the earth, and when nuclear reactors are able to produce more power per pound and operate for longer times, nuclear electric propulsion systems will become attractive. For a given amount of propellant used in such an engine, the increase in velocity of the payload will be many times greater than that obtained when propellant gas is simply heated in a more conventional rocket engine. Use of electric propulsion will be feasible when a suitable reactor power supply becomes available, in 15 or 20 years. The technological base for such reactors is being established through general research and development efforts under the SNAP program as well as in more specific efforts on SNAP reactors.

With the higher performance potentially available by use of electric propulsion engines exploratory probes can reach far out into space, manned flight to Mars becomes easier to accomplish, and systems of much greater weight can be raised from low earth orbits to stationary orbits.

ALTERNATE SYSTEMS FOR SPACE ELECTRIC POWER

There are only three possible sources of energy which can be used to generate electricity in space - chemical, nuclear, or solar. Each energy source, in conjunction with its power generation equipment, has its own intrinsic characteristics, and their differences determine which source is uniquely the best for a specific mission. For some missions power must be available for periods extending up to years; for others it is needed for only short periods of time. Some missions need power at their start and others only after the mission has been under way for a period of time. For some missions payloads are always in the sunlight; for others they are sometimes in the dark or in an area of very low solar flux. For some missions long orbital operation in the Van Allen radiation belts precludes use of solar cells; for others radiation damage to solar cells is unimportant. Some missions are manned; others are unmanned. Some are intended to make scientific measurements of the natural radiation levels in various regions in outer space and no substantial amounts of radiation can be emitted from their power source. Some will ride boosters large enough to make payload weight and size limitations of minimal importance; in others weight and size will be of critical importance. Some missions involve launching of so many individual payloads that costs of making power sources can be relatively important; others involve single launchings and the effort needed to develop a power source will obscure the costs in making the one finally used.

With launch vehicle limitations, weight is one of the most important considerations in selecting a space power unit. For chemical systems, where the fuel and oxidizer must be stored on board the spacecraft, the weight penalty shows up in relatively limited lifetimes; however, chemical systems are capable of high power levels. Batteries, if they are not recharged, are capable of up to 2 or 8 kilowatts of electricity (KWE) for a period of hours; chemical dynamic systems produce up to 20 KWE for several days; and fuel cells are expected to be capable of up to 5 KWE or more for a month or so. Chemical systems could operate for longer periods if they could be refuelled in space, but this would be an exceedingly costly operation. Such factors as reliability, simplicity, freedom from radiation, etc., make them desirable for many applications. With the advent of larger boosters that can carry more payload, and with the development of ways to increase efficiency, the lifetime of the chemical systems can be extended. This leads to the conclusion that chemical systems - possibly coupled with other energy sources - will continue to meet a portion of the future demand.

Solar energy conversion systems have one outstanding advantage over chemical systems - they draw on an endless supply of indigenous energy, sunlight, rather than on-board storage of fuel. They have the advantage which comes with few or no moving parts. However, they are degraded by Van Allen Belt and thermal radiation and deteriorate in performance with time.

The larger systems using solar heat to operate dynamic conversion systems are no less complex than the similar power conversion systems used with nuclear reactors or chemical systems. There are certain inherent disadvantages to all solar power systems. They are limited in power generation to the amount of sunlight they can intercept and use, so higher powered solar devices must have large and complex solar cell panels or reflecting mirrors. They will not operate unless they are in the sunlight, and generally are equipped with battery systems for payload power when in the earth's shadow. Moreover, the larger systems must be kept in an attitude pointed toward the sun and have useful lifetimes limited by the on-board supply of propellant used for keeping them so oriented. The major disadvantages of the higher capacity solar power systems compared to other systems are that they are heavy, large, and quite expensive at power levels much above 20 KWE. Taking all factors into consideration, it appears that solar dynamic systems will be considered for missions requiring as much as 20 KWE.

Nuclear devices have the major advantage that a given amount of fuel contains by far the largest amount of energy. Nuclear heat - in the form of either the decay heat of radioisotopes or the heat generated by the fission of uranium or plutonium - can be used in combination with thermoelectric, thermionic or dynamic converters to produce space power. Nuclear power thus offers systems that can produce the widest range of power levels, operate under the widest variety of environmental conditions, while always offering a long life, in the range of years. The isotopic-thermoelectric generators are rugged and have the ultimate simplicity of producing continuous power without any moving parts; the fission reactors eventually will be capable of producing thousands of kilowatts of electricity.

The disadvantages of nuclear systems arise almost exclusively from the presence of nuclear radiation which inevitably accompanies the release of heat through fission or radioactive decay. Protection of men and instruments is achieved by shielding, which is an undesirable added weight, or by separation of the payload and power source.

The launch pad handling of nuclear reactors will not be complicated by radiation because the radiation need not be present until the reactor is started up after the vehicle is established in a stable, long-lived orbit. The effect of radioisotope devices on normal launch pad handling, and any clean-up operations after missile aborts or explosions on or near the launch pad, depend upon the particular radioisotope present and the method of use. Information, techniques, and experience from SNAP and other phases of the atomic energy program will help in establishing acceptable procedures for such operations.

A temporary disadvantage with many nuclear systems, when considered in competition with other systems, is that their reliability and lifetime - their major potential advantages - remain to be demonstrated. Therefore, users cannot yet determine with adequate confidence that the relative full cost of using a nuclear system is competitive or advantageous. This disadvantage is not inherent in nuclear systems, and it is the Commission's responsibility to see that it is eliminated with the progress of the development program.

THE ROLE OF NUCLEAR ENERGY AS A SPACE POWER SOURCE

SNAP systems - radioisotope and reactor - are able to furnish power for space over the entire range of actual and potential requirements. Radioisotope power generators with thermoelectric or thermionic conversion systems can be used to produce any power level up to about 500 watts of electricity. The lifetime of these systems, at least up to a few years, is dependent to a large extent on the specific radioisotope or mixture of radioisotopes used as the power source and the reliability of the power conversion system elements. Throughout the power range up to 500 watts, isotopic devices are in competition with chemical and solar energy sources.

Various types of nuclear reactors and conversion systems can be used to furnish space power in the range from several hundred watts to potentially tens of millions of watts (tens of megawatts). For power levels increasingly above 20 KWE, nuclear reactors must be considered the best and ultimately the only source of power - even for relatively short missions. The weight, size, and cost of chemical or solar systems in this range are so great as to make their use infeasible. As power levels increase into the megawatt range, radiator sizes and weights become so large they impose practical limitations on possible power outputs.

Even in the range of power levels below 20 KWE, the stringent specifications for certain potential missions are not compatible with any non-nuclear system. The selection of a particular reactor or isotopic system could be dictated by need for maximum lifetime, for a light, rugged and compact system, for operation in shadow or far from the sun, for operation in regions of high penetrating radiation (natural or man-made) or meteorite flux, or for use in a high solar flux near the sun. However, due to such advantages as the relative ease of pre-launch handling in the absence of radiation, it is reasonable to expect that chemical and solar power systems will be considered adequate enough for a number of less demanding missions that can be satisfied with power levels below 20 KWE.

The advantages of a radioisotopic source of energy will lead to its use for some one-shot missions. For relatively permanent orbital systems requiring periodic launching of replacement satellites, the ability of radioisotopic power devices to provide longer useful mission life is more important. The lower rate of satellite replacement and the ability to continue generating electricity while in the earth's shadow provide better reliability and reductions in operating costs. These are advantages of radioisotopic devices that will undoubtedly overcome any inconvenience in pre-launch handling operation. Thus the use of radioisotopic devices will inevitably increase.

Although nuclear reactors offer the only way to satisfy needs for high power and long life systems, there are no presently stated mission requirements for electrical power that cannot be met by chemical or solar energy sources. However, potential requirements for some reactors are expected to become firm as the United States space program progresses, and to involve devices to furnish electrical power at various levels above 20 KWE.

These considerations lead to the conclusions that both radioisotopic and reactor power systems should and will play very important roles in space, and that a vigorous Commission effort is needed in both areas. The program should develop safe, reliable, low-cost systems capable of meeting future power needs in the range from milliwatts to megawatts. User acceptance is an additional Commission objective. Achieving this acceptance depends largely on a demonstration program involving extensive ground testing, and, when needed, flight testing. Such a program will assure the user that both the state of technical development and the solutions to operational problems have advanced to the extent necessary for him to select nuclear auxiliary power systems to meet his mission requirements.

PRESENT PROGRAMS - CURRENT STATE OF THE ART

Radioisotopes

A considerable amount of work has been completed on the use of strontium-90 in terrestrial applications. While much of this effort has direct application to space power generators using strontium-90, the only devices that have been launched into space thus far have used plutonium-238 for isotopic power. Thus, the present technology for fabrication and using radioisotopic space power systems must be considered to be that of plutonium-238. To date, four small thermoelectric generators using plutonium-238 have been launched, and all were placed in orbit successfully. Three of the generators are still working.

Generator and fuel development programs investigating the use of other isotopes such as polonium-210, curium-242, curium-244, promethium-147, and strontium-90 as space power sources are currently under way or planned.* Satisfactory techniques have been developed for encapsulation of the radioisotopic heat sources in ways to assure safety in the event of ground handling or launch pad accidents, but additional work is necessary to lower the cost of the encapsulation, improve heat transfer, and perfect capsules which will in addition either burn up completely or remain intact on re-entry.

The early thermoelectric devices used lead-telluride thermocouples for generating electricity. They now can be considered as

*For a listing of properties of radioisotopes used or being considered for use in SNAP systems, see Table 3, page 41.

reliable units in the range of 25 watts, but much more work needs to be done to extend their usefulness and to develop germanium-silicon thermocouples.

There are other ways to generate electricity from radioisotopic heat, such as using a thermionic electrical generator or heating a working fluid and using the fluid to drive a small mechanical motor-generator unit. The thermionic generators use radioisotopes to heat electrodes to temperatures at which electrons are boiled off the electrode surface, thus generating electricity directly. Operating at higher temperatures, they can achieve roughly double the efficiency of thermoelectric systems. Thermionic generators using curium-244 have unique potential advantages as compact, highly efficient, long-lived devices. Curium-244 is of such unique interest because of its particular combination of desirable characteristics - an eighteen year half-life, a heat generation rate for a given weight that is more than three times greater than any other suitable long-life material, and nuclear characteristics such that it would be easier for production reactors to make the curium-244 in quantity than to make plutonium-238. While curium-244 requires less shield weight than strontium-90, it requires more than plutonium-238.

A small (12 watt) experimental thermionic generator now under development is to be loaded with shorter-lived curium-242, and, as discussed later, an initial amount of curium-244 will be produced for use as radioisotopic fuel in similar future experimental devices. In addition to the Commission effort, other work on thermionic devices is being supported by NASA and DOD.

The effort on thermionic generators is long range in nature and aimed at determining fundamental technology and studying single cells. The current state of technology is such that thermionic conversion must be considered a potential conversion method which is not available today.

Knowledge of the safety of the radioisotopic power systems is at a point where experimental and operational units of limited size can use plutonium-238 as a heat source in systems to be placed in long-lived orbits, with units designed to burn up at high altitude on re-entry. More work must be done before there is a technical basis for use of other isotopes with a higher level of penetrating radiation and before systems of this type can be considered to be safe enough for flight testing.

<u>Nuclear Reactors</u>

A number of differing nuclear reactors and power conversion systems are under development so there can be some flexibility in satisfying users' various needs. The experimental program to date has demonstrated the generation of electricity in ground testing at low power (less than a KWE). This has been accomplished in the SNAP-10A program which uses a nuclear reactor employing more or less conventional materials in a relatively low temperature system. The fuel and moderator material is a hydrided alloy of highly enriched uranium and zirconium. It is cooled by flowing liquid metal, a sodium-potassium mixture (NaK) that transports heat from the reactor to a germanium-silicon thermoelectric power conversion system. The reactor operates well below its power capability and requires no motion of reactivity control mechanisms such as would compensate for fuel consumption. Instead, the small inherent increase in reactivity with falling temperature keeps the reactor operating after startup in orbit. It remains to be demonstrated that this relatively simple system is capable of startup and sustained operation in orbit.

Since static thermoelectric converters will be unable to produce more than several KWE at least for some time to come, development is underway on higher power dynamic conversion systems as well as on higher power hydride reactors. A hydride reactor has been operated at the higher temperatures needed for this application. A space power system, designated as SNAP-2 and consisting of a reactor similar to that in the 10A system and a dynamic power conversion unit, was under development until the near term need for this specific power system (3 KWE) recently ceased to exist. A vigorous program of investigation is continuing on a system with broader objectives based on this reactor and conversion unit. The basic limitations associated with higher power, higher temperature operation of this type system appear to be in the materials, and ways to overcome these limitations are under development in order to assure maximum system lifetime.

The development of dynamic turboelectric space power conversion systems is a major effort. Work on the mercury-Rankine cycle has progressed to a point where (1) a high speed compact system capable of producing power in the 5 KWE range has undergone initial successful ground tests, although much remains to be done before a proven system is available; and (2) a NASA effort on lower speed, more conventional, less compact systems capable of producing power in the 35 KWE range is in the initial phases of design and development. These mercury-Rankine conversion systems, as contrasted with static thermoelectric converters, have the unusual complication of a two-phase working fluid operating under zero-gravity conditions.

The more compact conversion system in the 5 KWE range, powered by a hydride reactor as was planned for use in SNAP-2, would provide a unique long-lived space power system. Technology useful to this system is being advanced within the AEC base program on power conversion and reactor development.

The reactor to power the more conventional conversion system in the 35 KWE range depends upon the same basic technology but requires a somewhat larger core operating at again somewhat higher temperatures. Such a core is now in extended operation at the full nuclear heat generation rate, coolant flow rate, and full temperature conditions. Development of the reactor and of the conversion system are being managed by the AEC and NASA respectively in a cooperative effort on the entire system, called SNAP-8.

In order to meet potential higher power requirements - several hundred kilowatts to a few megawatts - with systems that are small and light enough to be practical for space applications, it will be necessary to develop very compact reactors operating at very high temperatures (to minimize radiator area). These requirements are best satisfied by unmoderated reactors having ceramic fuels such as uranium oxide, carbide or nitride within fuel elements of such temperature resistant metals as niobium, tantalum, and tungsten. Practical high power systems must have highly efficient and compact systems for converting reactor heat to electricity and disposing of unused heat. These conversion systems may use electrical generators driven by small turbines operating at high temperature and speed, or may convert heat to electricity by thermionic emission, or may generate electricity by pumping the electrically conductive metal coolants through magnetic field regions, thus inducing electric currents by so-called magnetohydrodynamic effects.

The Commission has several programs under way aimed at developing the technology that will make it possible to attain power levels beyond the range of NaK-cooled systems. One program involves the first phase of a complete power plant known as SNAP-50, using niobium alloys as the major material of reactor construction, using one of the refractory uranium materials as reactor fuel - uranium oxide, carbide, nitride, or uranium oxide-beryllium alloy - and using lithium as coolant. System objectives include operation at temperatures around 2000°F, and production of power initially at 300 KWE, later about 1,200 KWE. The power conversion system would use a potassium-Rankine cycle including a lithium-heated potassium boiler and a potassium vapor turbine.

As a result of extensive experimental work on the technology of niobium and certain of its alloys, niobium containing one percent zirconium can today be fabricated into components for use with certain of the proposed reactor fuels. Use of this niobium-zirconium alloy to contain lithium at temperatures up to 2000°F has been demonstrated in loops.

Fuel materials development has progressed to a point where a uranium oxide-beryllium alloy or a uranium-oxide fuel system is feasible, though probably not optimum for long term use. Physical damage to the fuel as a result of fission product accumulation at high temperature, and particularly the effects of partial escape and partial retention of fission product gases, impose limitations on the amount of energy that can be extracted from these fuels. Work on uranium carbide has identified, but not resolved, the major problems attendant with the use of this more desirable fuel. These efforts on uranium-carbide are in earlier stages, and technical feasibility of using this material as a fuel is not yet assured.

Other system components such as pumps, boilers, heat exchangers, condensers and alternate high temperature materials are in an early stage of development. The development of lightweight radiators for use at correspondingly high temperatures has been identified as requiring a major effort. Ultimately, the ability to use maximum power in space may be limited by system ability to radiate to space the heat energy not converted into electricity. Much work needs to be done in this area. Such work is proceeding in AEC, NASA, and DOD; it is reasonable to believe that these problems will be solved.

A different high power system is being explored for possible use at somewhat lower power levels. In this system, potassium would boil in the reactor and the vapor would drive a turbine in a conversion system made from more conventional materials used at lower temperatures. This system offers a practical and efficient way of producing up to several hundred kilowatts of electricity and can clearly supply amounts of power beyond the reach of reactors coupled to a conversion system using mercury as the working fluid. Because of temperature limits on the conventional materials in this system it does not have the potential for producing power well into the megawatt range. Although the program is in the early stages of development and its technical feasibility is not yet assured, materials of construction and fuel cladding are relatively familiar; the properties of boiling potassium are under investigation; and the behavior of a presumably adequate uranium-oxide fuel system is partially known at the proposed operating condition. The Commission is now considering a reactor experiment to be a proof-of-principle demonstration of the feasibility of boiling potassium in such a reactor. The closely coupled power conversion system will also require considerable development effort, and such efforts are under way in other programs.

A much longer range effort, primarily fuel materials development, is under way on a type of reactor that would operate at very high temperature and use an inert gas coolant. The ultimate concept would involve an unmoderated reactor using a tungsten-UO_2 cermet fuel material with a refractory metal cladding. While it should be possible to develop a technological base for such a system, very little information now exists.

Various interesting power conversion concepts such as those using the principles of magnetohydrodynamic and magneto-fluid mechanics are being considered by the Commission for use in connection with SNAP systems, and, as was mentioned earlier, thermionic devices are under development. Closely related development efforts on advanced power conversion systems are being carried out by NASA and DOD. These systems all have great potential but presently involve serious technical problems when considered for actual use in improved SNAP systems for space application.

FUTURE ACTIVITIES - GENERAL TECHNICAL APPROACH

The SNAP development program will concentrate on approaches showing promise of unique advantage for future space missions. In various applications, SNAP devices have the inherent ability to provide the most power, reliability, and ruggedness, the longest lifetime, and independence of the space environment, as well as lowest weight, size, and cost. The Commission will proceed in close cooperation with potential users to select, develop, and demonstrate the specific devices required for their established and possible missions.

Radioisotopes

The future development of radioisotopic SNAP systems is aimed at units that can meet long-life mission requirements which cannot be met by other means, and that can operate efficiently and reliably at temperatures and at cosmic radiation, Van Allen radiation, and micro-meterorite exposures that render other systems ineffective. Development will include efforts to increase the reliability of isotopic generators, to decrease their specific weight, and to minimize the ground handling and payload integration problems caused by any penetrating radiation from the radioisotopic system.

An extensive safety program is being carried out involving: (1) the effects of re-entry from orbit on the radioisotope power systems and on their component parts; (2) the type of dispersion and deposition to be expected for the various radioactive source materials that might be so dispersed; (3) corrosion and erosion rates of intact power units and component parts in various media into which the device or part of a device might fall; (4) data needed to determine whether intact re-entry or re-entry burnup should be sought for specific isotopes; and (5) any other information needed by the Commission to fulfill the responsibility it has for the U. S. Government to assure protection of public health and safety in instances where radioisotopic power systems are used.

Efforts will be made by the Commission to assure the large-scale availability of various radioisotopic heat sources and to decrease markedly their cost. Present facilities can separate and encapsulate such radioisotopic materials as plutonium-238, promethium-147, curium-242, polonium-210, cesium-137, and strontium-90, but the total capacity is not as large as potential requirements. Probable needs for some specific isotopes far exceed production capability. The Commission is proceeding with plans for additional fission product recovery, purification, chemical conversion, and encapsulation facilities. They are to be constructed at the Hanford Atomic Products Operation, and to operate using production reactor "byproduct materials". Startup of this facility is expected by 1968. Preliminary studies have indicated that strontium-90, cesium-137, cerium-144, and aged promethium-147 can be produced by this facility in the quantities and at the price levels needed for radioisotopic SNAP devices to be properly useful.

The unique advantages of curium-244, especially if used in thermionic generators, have been discussed earlier. Quantities adequate for most or all needs could be made available after 1969 at costs estimated to be competitive with solar cells for some application. An initial curium-244 production program, beginning in the spring of 1964 and with the objective of producing 3 kilograms of curium-244 within a few years, will provide necessary experience in production, separation, fabrication, and use of this as yet very rare material.

Nuclear Reactors

Specific mission requirements for systems using SNAP reactors are likely to be initiated after users recognize that such power is indeed available and feasible for use. Meanwhile, the Commission's program will be responsive to potential requirements of users; indeed it is clear that SNAP program efforts must be geared to the developing needs of potential users with respect to such mission characteristics as power level, life-time, schedule, and tolerable size and weight. It is also equally clear that a program to take into consideration all of the factors previously discussed - the state of the art, the technical potential of the various systems, and the degree of firmness of the "requirements" - must be of a somewhat general nature. Indeed, the SNAP development efforts, in responding to specific requirments, must not seriously interfere with the more fundamental technology and testing programs being carried out to meet presently less firm, but equally important, future uses.

In line with this, the Commission's program in the field of hydride reactor power units for space is: (1) to carry out the experimental effort needed to determine, and demonstrate in space where necessary, the critical limits of the reactor concept and of the thermoelectric and compact mercury-Rankine conversion concepts; and (2) to demonstrate, through the ground test stage of typical flight configured systems, integrated systems at such power levels as seem to offer the most practical coverage of the power levels in potential demand. This program will make it possible for SNAP systems of less than 100 KWE to be built at such times as missions require specific units.

For the higher power ranges where nuclear energy is the unique power source, applications are long range in nature and even less well defined. Early efforts will involve development of both systems for unmanned missions and a technological base for considering manned missions. This leads to the conclusion that the Commission's program in this area should be directed toward developing advanced technology - both as to the nuclear heat source and as to the methods of converting this heat efficiently into electricity. The program should, of course, encompass considerably more than a materials technology program; components for several concepts - both reactor and energy conversion - may be under development at any given time. The program envisions reactor experiments and prototypes as well as necessary non-nuclear test facilities for conversion equipment such as boilers, turbines, radiators, and so forth. A better understanding will be developed of the unique properties and salient features of radiation shielding for manned space systems.

An extensive reactor safety program must be carried out on the effects of re-entry from orbit with specific objectives similar to the effort discussed earlier for SNAP radioisotopic systems, but now extended to evaluation of the probability and consequences of premature criticality, either at or near the launch pad, while in transit through the atmosphere, or as a result of failure to obtain the desired orbit followed by early impact on water or land. It must again provide the information needed by the Commission to fulfill its responsibility for the Executive Branch to assure protection of the health and safety of the public in instances where reactor power systems are used.

Power Generation Systems

In carrying out its program - in both the radioisotope and reactor areas - the Commission must aggressively pursue the various power conversion techniques. Not only must it adapt the well developed thermoelectric and mercury-Rankine Systems, but it also must have programs to extend the basic technology of the well known systems to higher temperatures, to develop more compact thermoelectrics, other liquid metal-Rankine cycles, and so forth. The Commission must also carry on active efforts to use new methods of conversion such as the thermionic and magnetohydrodynamic methods. It is noteworthy that many of these advanced power conversion systems can be used only in conjunction with a nuclear heat source.

The energy generated by space power systems is all finally dissipated to space, much of it still as heat energy. Larger reactor systems will require correspondingly large radiators, and such radiators remain to be developed. When radiator weight and size become large and burdensome, light weight and perhaps unfolding radiators will have to be developed.

RELATIONSHIP OF "USER" AGENCIES AND THE AEC

It is natural and reasonable that the "user" agencies wish to be assured that the AEC, in carrying out its developmental program, has full knowledge of their latest thinking in order that the developmental program be at all times fully responsive to the current needs - both actual and potential - of the user. It is also natural and reasonable for the AEC to wish to plan and conduct its program under its own control and not under the control of the users.

A situation of this type requires close inter-agency cooperation in the management of related technical programs. The cooperative arrangement between agencies could differ depending upon the firmness of requirements and the state of the technology of the heat source on the one hand and the power conversion system on the other. However, for the development of SNAP component and system technology as contrasted with "prototype" development to meet specific agency requirements, responsibility should rest with the AEC for planning and managing the program for both nuclear and non-nuclear components, including ground testing and flight testing of components or systems as are necessary for the AEC to meet its developmental objectives. Arrangements would be made with other agencies for flight vehicles and launch and tracking facilities. When specific SNAP projects are undertaken to meet an agency requirement having a reasonably well-defined time schedule, the program responsibilities will be determined in cooperation with the requesting agency.

In selecting a nuclear auxiliary power system, the user should consider the cost and availability of isotopic fuel and fissionable material used in the system. As the applications of SNAP systems approach more of a routine character, as opposed to prototype applications, user agencies will have to plan and budget for the radioisotopes and nuclear fuels they require.

CONCLUSIONS

The SNAP program was begun as a result of early recognition of anticipated electrical power needs for spacecraft. The AEC's program has pioneered in the applications of nuclear power for this purpose and has been primarily responsible, in government, for many novel approaches. Such things as compact reactors, radioisotope heat-energy capsules, thermoelectric generators, thermionic generators, compact mercury vapor turbines connected directly to electric generators, light-weight shielding, and aero-space safety, are but a part of the developments that the Commission has been pursuing in support of the nation's space program.

This SNAP study has confirmed previous statements concerning the advantages of and needs for nuclear power in space. With the passage of time and as the technology has been carried closer to flight applications, some developments appear to be more difficult and require more time. On the requirements side, time schedules have slipped, especially for missions for which nuclear power is necessary. Since one of the most expensive phases of any project-oriented SNAP development is in flight testing, it is important that such testing be done at a time which will make maximum contribution toward answering the uncertainties, especially technological uncertainties of operation in the space environment.

The present AEC annual cost for the SNAP research and development effort, including directly related efforts in isotope development and aerospace safety, is approximately $100 million. Continued operation at approximately this level should permit development of the technology of isotopic and hydride reactor systems with their associated converters to a state where specific systems satisfying requirements in the range up to 10's of KWE could be assembled for various mission tests by the late sixties. This level of effort does not provide for flight testing. Increased work necessary for project-oriented systems would require additional support for the extensive systems engineering development and flight testing needed to meet specific mission requirements. The present program of advanced technology and its associated ground testing is proceeding at a relatively low but reasonable level consistent with long-term development. It must be recognized that full development of an advanced system to provide power in the range of hundreds to thousands of KWE will in itself probably cost over a billion dollars during a period of 15 or more years.

This study has led to several conclusions which have formed the basis for program planning including several actions taken by the Commission during 1963. These several conclusions are set forth below.

1. <u>Nuclear auxiliary power offers unique advantages to a wide variety of space missions. The SNAP development program should be concentrated on approaches to provide these advantages, which include among others, light weight, compact fission and radioisotopic systems in a power range up to 20 KWE and reactor systems with long life at higher power.</u>

In certain space applications, electrical power requirements can be met only by nuclear systems. In others, there may be a competition among chemical, solar, and nuclear systems, and the user will have to weigh the advantages and disadvantages, both technical and economical, in making a selection for specific missions. The Commission's research and development program on nuclear technology must be directed at exploiting advantages such as long life, high power, compactness, and ruggedness; and reducing the present disadvantages of shield weight, high cost, and radiation emission. The development of the technology and the testing of systems must be carried sufficiently far that users' judgments in the selection of systems will be based upon firm technological grounds.

2. <u>The performance of ambitious space missions will require amounts of reliable power so large that they can be achieved only from nuclear systems. Continued timely development of advanced SNAP technology is necessary to meet this need.</u>

Advanced technology is required in the development of minimum weight systems in the power range of hundreds to thousands of kilowatts. Although the mission requirement is far in the future, the development of the technology will require a long lead time.

3. <u>In the absence of near term specific mission requirements, the SNAP reactor technology must be developed to meet power requirements within several power ranges (kilowatts, tens of kilowatts, and hundreds to thousands of kilowatts) thereby</u>

making available a technological base for the specific systems for ultimate mission use.

The grouping of potential requirements into several categories, each of which differs from the other by an order of magnitude, will permit reactor development and converter development to go forward to satisfy the needs set forth above with a minimum number of system concepts. Obviously, within these ranges, developments will be directed toward those potential applications in which users indicate the greatest interest. Potential users must recognize that adequate time must be allowed in their own programs for the development of a suitable nuclear system. However, the Commission's program should assist in minimizing the time necessary to assemble a specific system for ground and flight test.

4. Development of SNAP technology should be carried forward with the Commission giving full attention to the integration of the converter with the nuclear heat source.

The user is most concerned that equipment be available to meet this electrical power requirement. In a program of advancing technology directed toward meeting these electrical power needs, the nuclear heat source-converter system must be developed in a coordinated manner. The Commission must assure itself that adequate development is going forward on both components and take the initiative in meeting the technological problems. It is recognized that other agencies, as well as the AEC, will be involved in development of converter technology. Also, when specific development projects are undertaken on a reasonably well defined time schedule, program responsibilities will be determined jointly with the requesting agency.

5. <u>Where Commission responsibility for power system developments involve first-of-a-kind technology and equipment, the program should extend through the demonstration phase, including ground and flight testing as necessary, and should encompass programs for the resolution of safety problems.</u>

First-of-a-kind technology for nuclear heat source-converter systems should be carried through a demonstration phase which may, in addition to ground testing, require flight testing. Such a program will give the Commission better guidance for its future work and will provide more extensive information for the user on which he can base future plans. When flight launch and tracking facilities are required to meet the needs of the Commission's program, the Commission would plan for and arrange with NASA or DOD to carry out the flight. Where joint projects are involved, the Commission would expect the cooperating agency to plan for and execute the flight test. The Commission's program will benefit from participation with users in planning and carrying out launch operations, assuring safety, and finally testing of the SNAP device in space.

6. <u>The orderly development of SNAP technology through the demonstration phase should provide users with information and experience needed for them to specify and obtain nuclear power systems and to assist in planning their missions.</u>

In selecting a power supply to meet requirements, user agencies must have available sound technical and economic data and, to the extent possible, performance experience at or near ultimate operating conditions. In implementation, the Commission's program will approach such needs, while deferring the incurrence of major project expenditures until such times as specific needs can be set forth.

The SNAP program has reached a point in technology where its importance to the nation must be recognized, accepted and supported, or the development and performance of ambitious space missions will be handicapped by a lack of adequate and reliable power.

TABLE 1

RADIOISOTOPIC SNAP GENERATORS

DESIGNATION	USE	POWER (WATTS ELECTRICAL)	WEIGHT (POUNDS)	ISOTOPE	DESIGN LIFE	CURRENT STATUS
	SPACE APPLICATIONS:					
SNAP-3	Demonstration device	2.5	4	Polonium-210	90 days	Program completed.
Undesignated (Modified SNAP-3)	Navy navigational satellites	2.7	4.6	Plutonium-238	5 years	Generators launched June and November, 1961. First still in operation; second failed after 8 months.
SNAP-9A	Department of Defense satellites	25	27	Plutonium-238	5 years	Generators launched September and December, 1963. Both in operation.
SNAP-11	Moon probe	21-25	30	Curium-242	90-day mission	Being tested
SNAP-13	Thermionic demonstration device	12	4	Curium-242	90-day mission	Being fabricated
SNAP-17	Communications Satellite	25	28	Strontium-90	5 years	Initiated in mid-1963.
SNAP-19	IMP, Nimbus	20	18	Plutonium-238	5 years	Design study stage.
Undesignated	Light-weight demonstration device	6-10	3	Plutonium-238 or Strontium-90	Greater than one year	Being tested.
	TERRESTRIAL APPLICATIONS:					
Undesignated	Axel Heiberg weather station	5	1,680	Strontium-90	2 years minimum	Operating since August, 1961.
SNAP-7A thru E	Navigational buoys, lights and beacons, weather stations, etc.	6.5-60	1,900 to 6,000	Strontium-90	10 years	First unit in operation February, 1962; four now operating.
SNAP-15A & B	Nuclear weapons	0.001	1	Plutonium-238	4 years	Under test.
SNAP-21	Ocean bottom	10	--	Strontium-90	5 years	Initiated in late 1963.

TABLE 2

SPACE REACTOR SNAP GENERATORS

DESIGNATION	USE	POWER (KWE) DESIGN	POWER (KWE) POTENTIAL	WEIGHT[1] (POUNDS)	DESIGN LIFE	CURRENT STATUS
REACTOR PROJECTS:						
SNAP-10A	Thermoelectric demonstration system	0.5	2	1,000	1 yr.	Nearing completion
SNAP-2	Rankine cycle demonstration system	3	10	1,470	1 yr.	Reoriented toward component improvement. See under Research and Development Programs.
SNAP-8	Communication satellites or space station	35	--	6,000 (est.)	10,000 hrs.	Power test of experimental reactor now under way.
SNAP-50	Electric propulsion and auxiliary power	300	1,200	6,000 (est.)	10,000 hrs.	Development of components continuing. Construction of reactor experiment terminated.
RESEARCH & DEVELOPMENT PROGRAMS:						
Hydride Reactors						
with thermoelectric power conversion			15	3,600		
with turboelectric power conversion			100	5,000		
Boiling Potassium Reactors			140-400	--		
Refractory Metals Reactor			--	--		

(1) Includes weight of a radiation shield to reduce cumulative dose over a year's operation to levels that will not damage sensitive instrumentation.

TABLE 3

RADIOISOTOPIC MATERIALS[1]

RADIOISOTOPE	HALF-LIFE, YRS.	TYPICAL POWER DENSITY, WATTS/CC[2]	RADIATION PRESENT[3]	SHIELDING REQUIRED
Strontium-90	28.	1.4	beta and bremsstrahlung	heavy
Cesium-137	30.	0.21	beta and gamma	heavy
Cerium-144	0.78	24.5	beta and gamma	heavy
Promethium-147	2.7	1.8	beta	minor
Polonium-210	0.38	1,210.	alpha	minor
Plutonium-238	89.	3.5	alpha	minor
Curium-242	0.45	1,150.	alpha	minor
Curium-244	18.	26.4	alpha and neutron	moderate

(1) For information on radioisotope production capability cost and comparative economics, see sections II and IV under Isotopic SNAP Program, "An Evaluation of Systems for Nuclear Auxiliary Power," TID-20079, a January, 1964 report by the Commission staff.

(2) These power densities are here reduced below theoretical maxima in order to account for expected isotopic impurities and the diluting effect of use in a representative chemical compound form. More detailed information is contained in the above referenced report.

(3) While other forms of radiation are present, those listed are of dominant importance in heat generation and for consideration of radiation shielding.

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SYSTEMS FOR NUCLEAR AUXILIARY POWER

... an Evaluation - January 1964

OFFICE OF PROGRAM EVALUATION
DIVISION OF REACTOR DEVELOPMENT

U.S. ATOMIC ENERGY COMMISSION

1572

AN EVALUATION

OF

SYSTEMS FOR NUCLEAR AUXILIARY POWER

BY

THE OFFICE OF PROGRAM EVALUATION

DIVISION OF REACTOR DEVELOPMENT

U. S. ATOMIC ENERGY COMMISSION

January, 1964

PREFACE

This evaluation contains background information considered by the Commission in the preparation of its report on Systems for Nuclear Auxiliary Power. It was prepared by the members of the Office of Program Evaluation, Division of Reactor Development, named below, who served as the SNAP evaluation team, and hence does not necessarily represent an official position of the AEC on any of the subjects covered.

Due to classification it has been necessary to omit some of the relevant information, mainly in the areas of advanced reactor technology and detailed military defense requirements for both radioisotopic devices and reactor systems, from this publication.

The preparation of this evaluation report was greatly facilitated by the numerous briefings, reports, and discussions provided by the Department of Defense, the National Aeronautics and Space Agency, and the many companies engaged in space power projects. This assistance is gratefully acknowledged.

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CONTENTS

FIGURES AND TABLES

FIGURES | Page

TABLES

INTRODUCTION

The United States placed its first satellite in an earth-bound orbit in 1958. The signals from this satellite were heard for about two weeks ... the limit of the battery supplied power. Since 1957 a major national effort has been established and spacecraft weighing thousands of pounds have been orbited which use electrical power plants producing as much as a few hundred watts. It became apparent early in the space program that operation of electronic payloads in space for extended periods of time, at almost any power level, would dictate that solar or some form of nuclear energy would be required. This is because the weight of any other source of power including fuel would become very heavy even if the most efficient fuels and oxidants were used.

In the period 1952-1955 the Commission had studied a number of nuclear energy power source concepts from the viewpoint of establishing their feasibility for use in future spacecraft. Both reactors and radioisotopes systems were considered. Although reactors are inherently large and heavy, requiring massive shields, it appeared possible that smaller, compact versions could be designed and built. Likewise, certain radioisotopes such as cerium-144 and polonium-210 were capable of producing high specific power and appeared to warrant further investigation.

The Commission's responsibility to promote the development and utilization of atomic energy was extended to include space applications during the 1955-1958 period when the Department of Defense requested that the Commission develop specific devices on a schedule to meet certain Air Force applications. A cerium-144 radioisotope powered generator using a dynamic-conversion system was selected in 1956 for development to meet these early requirements. A joint Air Force and AEC group established fairly well-defined specifications for power, weight, life, and the interrelation of the nuclear device and the Air Force's spacecraft. Following this, the National Aeronautics and Space Act of 1958 placed the Chairman of the AEC on the Space Council and further confirmed the Commission's role as a contributor to the nation's space program.

This developmental effort has been greatly expanded, providing for systems studies, component development, system integration, flight vehicle qualification, and orbital flight tests of both radioisotope-fueled and reactor power systems which use both thermoelectric and turboelectric energy conversion systems. This program is identified by the acronym SNAP meaning "Systems for Nuclear Auxiliary Power." The reactor systems are further identified by even numbers and the radioisotope systems by odd numbers.*

The early development of radioisotope generators was carried out as an alternate source of power to batteries. The "atomic battery," a polonium-210 fueled thermoelectric generator which weighed about four pounds and was demonstrated early in 1959, had the energy equivalence of nearly a ton of nickel cadmium batteries. This unit was called SNAP-3. The effective development of solar cells has largely postponed widespread development and use of radioisotope generators. However, radioisotope

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*See Appendix for list of SNAP radioisotope and reactor systems.

SNAP units have not only proven to be competitive weight-wise with solar cells but they have other advantages such as inherent reliability, no requirement for auxiliary energy storage, resistance to radiation, and offer the promise of low unit cost. These qualities are demonstrated by actual flight in the Navy's satellite.program. More powerful generators would require the placing of large quantities of radioactive isotopes in space which could prove hazardous in certain types of accidents. The Commission is actively pursuing a program to assure the safe use of radioactive isotopes in space.

Quite apart from the program to develop radioisotope units for space use there has been a growing interest in these devices for use in remote, inaccessible regions of the earth. The dramatic use of isotope generators on Axel Heiberg Island and at the southpole to relay weather data on a reliable basis is a measure of their future worth to mankind. The large potential for applications of this kind encourages the investigation of promoting wider use through lower costs of the isotopic fuel which can be achieved by larger scale production.

Although early solar cell systems produced only a few watts of power, later versions have been built with power levels as high as several hundred watts. Ambitious proponents of solar cell systems predict that generators producing a few kilowatts can be built at somewhat lower unit cost. Since these systems cost as high as two million dollars per kilowatt there is strong incentive to improve this situation. Above a kilowatt or two there is always the possibility of the collection of solar energy by mirrors for use in a dynamic power conversion system. The practical limit for these devices, mainly due to cost, size, erection, energy storage, and orientation difficulties, appears to be twenty to thirty kilowatts (e). All solar systems which operate thru the earth's shadow must employ energy storage -- either batteries or chemicals to store latent heat; also these larger systems must be fully oriented towards the sun.

The solar alternatives to nuclear power in space tend to raise the power range of interest for nuclear systems. The acceptance of a nuclear system by the spacecraft designer will be influenced by the limitations inherent in the growth of solar systems.

Finally, there are high power requirements linked to future interplanetary missions which are predicted by NASA for staging, perhaps in the 1980's. Studies verify that the only way to achieve some of these missions is by low specific weight, high power reactor systems with exceedingly high reliabilities. Proper phasing of an effort in the Commission geared to these applications must be considered in light of the anticipated high costs and the probability that such ambitious missions will be attempted within the forecasted time scale.

Since the beginning of the SNAP program in 1955, a number of new problems have evolved which cause concern within the Commission and the various government bodies charged with the support of this effort. These problems are concerned with the status of requirements, the magnitude and scope of the SNAP program, the long range effort, the development of alternate non-nuclear power devices, and to some extent the interrelationship between the AEC program and that of the ultimate users, i.e., NASA and the DOD.

The magnitude and scope of the SNAP program has been greatly increased by the complexity of developing a compact nuclear reactor and a novel energy conversion system capable of withstanding rocket launching and operating for long periods in the space environment. This was not fully appreciated in the early phases of the development program. Technical difficulties encountered in fully qualifying these units to withstand the combined effects described above have caused program delays and corresponding increases in cost. Another factor, which adds further to the complexity is the necessity of providing complete nuclear safety throughout the launch, orbital operation, and re-entry should it occur. The added expenditures necessary to flight test and operationally qualify SNAP units to a high degree of reliability must be balanced with the predicted space program requirements.

Further complication arises from the nebulous character of future needs for nuclear power programs as visualized by NASA and DOD. These programs are long range and could become prominent in the next two decades. Although neither agency can define specific missions in terms of an application or schedule, they have indicated that future programs will undoubtedly need high power nuclear systems in the many hundreds of kilowatts range, possibly as high as a few tens of megawatts. In cooperation with the DOD and NASA, the AEC established in 1962 a substantial effort in support of the predicted high power requirements.

Recognizing that the interplay of technical and programmatic changes is greatly influencing the SNAP program, the Chairman of the AEC announced in November, 1962, that the Commission had decided to take a new and hard look at the SNAP program; and directed the staff to undertake this study.

SNAP REACTOR PROGRAM

I Requirements and Potential Applications for SNAP Reactor Systems

A "requirement" is herein defined as a request by NASA or DOD that the AEC develop a complete flight rated reactor-powered system, or a reactor for integration as a component into a complete spacecraft system which is being developed by others. To some extent, the ultimate use of the system is defined as part of the requirement.

Potential applications for SNAP reactor systems can be identified, although they cannot be defined too accurately. The deduction that a potential need exists is based on a review of long-range planning documents, policy statements by government officials, and opinions of government sponsored study groups; and is further influenced by opinions of knowledgeable members of industry.

SNAP-10A and SNAP-2

The SNAP-10A and SNAP-2 systems were initiated in 1960 and 1956 based on reasonably well defined Air Force requirements, specifications, and schedules. However, changes in Air Force programs have, in effect, resulted in the cancellation of a specific requirement in the 0.5 KWe to 3 KWe power range of SNAP-10A and SNAP-2, respectively, and no flight tests are planned for the immediate future.

The SNAP-10A system is almost fully developed and consists of a uranium-zirconium hydride reactor coupled with a thermoelectric power converter. The AEC plans to complete its ground testing and demonstration program of the 10A system. The SNAP-2 system consists of the same reactor as 10A, but operated close to design limitations. The reactor is coupled to a Rankine cycle turboelectric power conversion system known as combined rotating units (CRU). Because of the present lack of requirements, and because this project is not as close to completion as SNAP-10A, the Commission has terminated the project, known as SNAP-2, to develop a specific 3 KWe power reactor system for the Air Force.

While SNAP-2, as a system, has been terminated, the Commission will continue to proceed with a base program aimed at developing and demonstrating the potentials of the uranium-zirconium hydride fuel technology and improving and extrapolating the power capabilities of turboelectric combined rotating units. Applicable portions of technology will be integrated with this effort. As the technology advances, a complete system at a power level that best suits potential requirements would be assembled and ground tested under simulated space conditions to the extent practical. The determination of whether to flight test a complete system and on what schedule will depend upon the needs of the AEC development program to get technical information from space operation and the firmness of requirements.

Although the basic SNAP-10A and SNAP-2 systems were designed to be demonstrated at power levels of 0.5 KWe and 3 KWe, respectively, the SNAP-10A can be upgraded to a power range of several kilowatts electric and the SNAP-2 concept can be upgraded to the range of 10 KWe. It is quite likely that requirements will develop in the defense program for SNAP units at these power levels. Communications, reconnaissance and surveillance are examples of such applications. It is also probable that these systems will be unmanned. Further assessment of future space missions is under study by the Air Force's space system command.

The NASA long range plan, published in 1962, estimated that units with power capability as high as 30 KWe would be needed in this decade. Broad use of the solar-turbogenerator system was indicated in this range with reactor powered systems also having applicability over 10 KWe. Examples of potential needs for SNAP-2/10A type systems are indicated for space stations, lunar bases, and communications. These applications do not yet constitute major efforts and are currently in the study phase.

SNAP-8

The original program established in 1959 by NASA and the AEC to develop SNAP-8 has undergone numerous changes. The 1959 requirement indicated this system would be considered for use in early electric propulsion and interplanetary communications applications. Eventual manned applications were also considered and a flight test of the SNAP-8 system was planned. The current NASA weight estimates in the range of 150 to 200 pounds per kilowatt, however, make the system unattractive for electric propulsion.

The potential use of SNAP-8 for direct broadcast TV has been considered as about 30 KWe are needed for each channel (for U.S. coverage). The current NASA program in this field is limited to relatively low-power point-to-point communications satellite systems, and does not include plans for support of a SNAP-8 powered direct broadcast TV-system. There are additional considerations involving international assignment of frequencies. The FCC, as a regulatory group, plays a limited part in establishing requirements or needs for satellite systems. It is probable that a need for direct broadcast TV will have to originate in the broadcast industry itself - when it becomes economically attractive. At this time, it is unlikely that the impetus for expanded development of SNAP-8 will be found in commercial direct-broadcast television.

While the requirement for SNAP-8 as a power source for electric propulsion and interplanetary communications is questionable, its potential use in a large manned space-station or a lunar base may be important. If a small manned space-station is successfully developed (which may require about 4 to 8 KWe), it is possible that a large 20-man station would be considered for the 1970s. This large system would require a power level about that produced by SNAP-8. The development of a large space station is at this time in the early study phases. The lunar-base concept is expected to be similar in concept.

Recent studies by systems contractors indicate potential uses for reconnaissance systems, space-stations, and military communications systems. The Air Force has recently completed a review of the potential military uses for satellites systems and these are expected to be redefined.

In summary, potential needs for SNAP-8 are not clearly predictable. Use for electric propulsion, interplanetary communications, and direct-broadcast TV are speculative. Its use for the large space station or a lunar-base are possibilities. Potential needs which may be most imminent involve use in military satellites.

The SNAP-8 reactor, which was demonstrated at full power in 1963, will provide a basic energy source which could power SNAP-2/10A thermoelectric and CRU conversion systems up to 12 KWe and 30 or 40 KWe, respectively. The range provided by these combinations holds the promise of fulfilling any predictable need for kilowatt blocks of power in the next decade or two.

SNAP-50/SPUR

As agreed between NASA, DOD and AEC in late 1962, responsibilities in research and technology were delineated in the development phase of SNAP-50/SPUR. The system objective is to produce power from 300 to 1,000 KWe, have a lifetime of at least 10,000 hours, and an unshielded specific weight of not greater than 20 pounds per kilowatt. Over-all responsibility for development is vested in the AEC. The DOD is to establish requirements, provide integration and conduct the flight tests. NASA will supply appropriate design data. The power level, life, and specific weight objectives for SNAP-50 have been agreed upon by the three agencies on the basis of judgement and not as a requirement. The potential needs have been identified only in general terms.

NASA has indicated potential use of low specific weight (10-15 lbs/KWe, shielded), high power (500 KWe to 20-30 MWe) systems primarily for electric propulsion. Hence, very long reliable lifetimes, on the order of one to two years or more, are required. Probes out of the ecliptic plane (1970-1975), cosmological probes (1970-1975), and manned interplanetary landings (beyond 1975) are examples of the type of missions anticipated. Also, a few hundred kilowatts at specific weights of not greater than 50-100 lbs/KWe are anticipated as applicable to lunar bases. Some of these concepts are in the study phase and some work is being done to prove feasibility of electric propulsion engines.

Since the Apollo program is oriented toward a lunar landing by 1970, the time scale for the advanced applications is probably optimistic by at least five years. Further, since Mars and Venus will not be close enough to the earth for low-energy transfer orbits during the late 1970s, this moves the actual flights well into the 1980s. Should a large National program be established following Apollo, alternate schemes for interplanetary propulsion by chemical and nuclear-heat-transfer rockets may be considered first.

In January 1962, the Department of Defense stated that there are no specific applications nor specifications for high-power, low specific-weight reactor powered systems; however, it was recommended that an aggressive component development program be pursued to achieve a typical power in the range of 300-1,000 KWe at an unshielded specific weight of 10 pounds per kilowatt. (The specific weight objective was later changed to 15-20 pounds per KWe, unshielded.) Earlier studies concluded that approximately 250 KWe is required for each pound of electric propulsion thrust which implied power levels of 20-200 MWe for typical Mars-type manned missions. NASA estimates are in the same range.

Exclusive of any electrically propelled spacecraft mission, the potential need for power systems in the range of 300-1,000 KWe remains unidentified, with the possible exception of a large lunar station.

To summarize the uses for SNAP-50/SPUR: during the 1970-1975 time period there are three possible missions which may require up to 500 KWe: (1) unmanned interplanetary probes, (2) lunar base, and (3) manned space stations. During the 1975-1985 time period it is possible that power levels of one to two megawatts will become useful for unmanned interplanetary missions to the distant planets such as Jupiter. It is also possible that now unrecognized military applications will be established which utilize power in this range. Multi-megawatt, low specific weight systems are expected to find applicability in the period beyond 1980. These systems would be used primarily for manned interplanetary missions. The exact nature and schedule of missions in both NASA and DOD are unknown at this time. Table 1 summarizes the possible applications for reactor SNAP in various power ranges and attempts to highlight those factors which are important to various missions.

POSSIBLE SNAP REACTOR APPLICATIONS

	Est. Use Date	Power KWe	Specific Weight Lbs/KWe	Life & Reliability
UNMANNED APPLICATIONS				
Meteorological Satellites	1966-67	2	Not critical	Important
Communications Satellites				
Synchronous Pt. to Pt.	1968-70	10	Important	Important
Synchronous T.V.Broadcast	1970-72	60	Important	Important
Military	-	-	-	-
Military Reconnaissance & Surveillance	-	-	-	-
Interplanetary Missions (Electric Propulsion)	ca.1975	500-1000	25-30	Vital
MANNED APPLICATIONS				
Manned Orbiting Laboratory	-	-	-	-
Large Space Station	ca.1975	30	Important	Important
Lunar Base	ca.1980	30-300	Important	Vital
Flight to Mars	ca.1980	20-200 MWe	10-15	Vital

II Evaluation of SNAP System Development Programs

Prior to 1964, the SNAP reactor development program consisted of four related but separate projects -- SNAP 10-A, SNAP-2, SNAP-8 and SNAP-50 -- plus alternate approaches. As previously discussed, with changing requirements and schedules SNAP-2 as a specific project has been dropped; however, the reactor and converter technology associated with that project is being pursued. The following evaluation of SNAP system development programs is presented under the headings of SNAP-2/10A, SNAP-8, and SNAP-50 in order to set forth work in the three power ranges. The system project terminology has been retained since it is common usage.

SNAP-2/10A Programs

A. Technical Review

The SNAP-2/10A reactor program is designed to provide a nuclear heat source for medium power (0.5 to 10 KWe) space systems. At the lower end of this range, the SNAP-2/10A reactor operates well below the power of which the design is capable and a static power conversion system (Ge-Si Thermoelectrics) is utilized to generate the electrical energy. At power levels beyond several kilowatts electric, the reactor is operated closer to its design limitations and a dynamic Rankine cycle system (Mercury working fluid combined rotating unit) is used to generate electrical energy. The effect of increased reactor power on system design can be seen by comparing those of the SNAP-10A system at 0.5 KWe with those of the terminated SNAP-2 system at 3 KWe:

TABLE 2

Design Objectives - SNAP-10A and SNAP-2 Systems

	SNAP-10A	SNAP-2
Electric power	0.5 KW	3 KW
Thermal power	33.5 KW	60 KW
Reactor outlet temperature	1000° F	1200° F
Reactor inlet temperature	900° F	1000° F
Control	Static after initial startup	Active
Life	1 year	1 year
Power conversion system	(Si-Ge thermoelectrics)	(Hg-Rankine cycle)
Specific weight	1870 lb/KWe	490 lb/KWe
Fuel power density	12.7 watts/cc	21.8 watts/cc

The basic SNAP-2/10A reactor uses homogeneous zirconium-hydride-moderated highly enriched fuel, beryllium reflector controls and liquid metal (NaK) coolant. This combination of fuel, coolant and controls is basically sound providing inherent stability of operation, low inventory of fuel, and ease of control. In fact, at a thermal power of 33.5 KW, the reactor is expected to operate without further control requirements for its design life after startup, depending only upon inherent temperature coefficient corrections to maintain its reactivity. However, at a thermal power of 60 KW, it will require some reflector control adjustments during life to maintain reactivity. This is mainly due to loss of moderator through diffusion of the hydrogen out of the fuel during operation at the higher operating temperatures.

Active control throughout reactor life, of course, introduces an additional complexity to the higher power SNAP-2/10A systems. Intermittent operation concomitant with long periods of inactivity at high temperatures may lead to self-welding and binding of the control mechanism. In addition, the control system depends on accurately sensing reactor outlet temperature. Reliability and accuracy of temperature sensors in space and reactor environment for long periods remains to be demonstrated. Based on difficulties encountered in past tests, this may be troublesome. Further control system development and testing will improve confidence that long term reliability can be achieved.

A basic problem associated with high power, high temperature, hydrided reactors is the hydrogen retention barrier required to minimize hydrogen losses during reactor operation. This problem is less severe at lower thermal power levels because of the lower operating temperatures. Hydrogen loss-rates are dependent upon the dissociation pressure of the hydrided zirconium alloy which, for a given alloy, is largely dependent upon the temperature of operation and the effectiveness of the hydrogen barrier. Reliable barriers are difficult to obtain, and an extensive program has been initiated to improve the basic characteristics of hydrogen barriers and the techniques used in applying these barriers to fuel elements. Efforts are also being made to improve the fuel alloys to give a lower dissociation pressure.

A major concern in a space reactor system is remote startup after going into orbit. The problems of startup are not as formidable with a SNAP-2/10A thermoelectric system as with a turboelectric system since it does not have the complication of a two-phase working fluid operating under zero-gravity conditions. The successful startup in orbit of a

SNAP 10-A system would demonstrate feasibility.

A major design problem exists in the mercury-Rankine cycle involving the turboelectric Combined Rotating Unit (CRU). Problems have plagued this component due to the complexities inherent in combining the turbine, mercury pump, NaK pump and alternator into a single high-speed shaft within a single housing. All foreseeable failure modes were examined and a complete redesign of this unit was initiated early in 1962. As a result of this redesign:

(1) the NaK pump has been removed from the rotating shaft and replaced by a thermoelectric pump operating between the NaK and Hg loops;

(2) the CRU housing and shaft were made more rigid;

(3) bearing loads were minimized;

(4) the complete unit was balanced for thermal stresses; and

(5) a three-pad orifice-compensated bearing has been selected for bearing stability.

In addition, a new design in under development which places a smaller premium on weight -- this unit referred to as CRU-V will facilitate easier assembly as well as incorporate all of the redesign features of previous developmental models of the CRU.

In summary, the SNAP-2/10A reactor is relatively well developed with no major technological problems, although a 1200°F reactor outlet temperature approaches the limit with existing hydrogen barrier materials for operating periods up to a year. Orbital startup of reactor systems is yet unproven and undemonstrated. The lower power, thermoelectric SNAP-10A system, with its single-phase fluid system and no requirement for continuous control after startup, would prove much simpler for this purpose than a more complex, higher power system. Combined Rotating Units are still under development. Although many of the problems encountered in previous units have been identified and modifications have been made to correct them, a proven, reliable CRU is not yet available.

A SNAP-2/10A thermoelectric system has the potential to deliver up to 2 KWe at a reactor outlet temperature of 1200°F; a SNAP-8 thermoelectric system at 1350°F reactor outlet temperature could deliver up to 15 KWe. Power outputs of this size are beyond the practical capabilities of most non-reactor power generators (with the possible exception of solar dynamics) and places the thermoelectric generator into direct competition with Rankine cycle reactor concepts for applications in these power ranges.

The SNAP-2/10A system with dynamic Rankine cycle conversion has a growth potential to 10 KWe by improving turbine and alternator efficiency by coupling two CRU's to the reactor. Coupling eight CRU's to the SNAP-8 reactor has the potential of producing 30 KWe. This system would achieve the lower range of SNAP-8 power capabilities with increased reliability for producing partial power, although reliability of maintaining full power output would be impaired.

Other methods of achieving power in competition with SNAP-2/10A systems are of interest. Power levels up to a kilowatt or so are attainable by other means which could obviate the problems inherent in reactor operation. Both isotopes and solar-cell technology are feasible; however, the operation of isotope units at kilowatt power levels present difficult radiation problems. The high cost of solar cell units, their erection and orientation problems in the large sizes tend to limit their wide use.

Power levels greater than several kilowatts can be accomplished by means of a solar-energy collector and a suitable thermodynamic cycle, either Rankine or Brayton. This system is in the early stages of development by both NASA and the DOD. The NASA system (SUNFLOWER) uses a modification of the turbogenerator unit intended for SNAP-2. It is likely that development of a solar-powered unit of this type will take five or six years of intensive effort after a full-scale program is established. Since SNAP-2/10A systems are under active development, their availability during this decade would represent the only power capability in the range up to several kilowatts.

B. Discussion

Failure to demonstrate the operation of reactor power systems in space could lead to loss of interest by potential users. The SNAP-2/10A is the simplest concept, using the least advanced technology (with the possible exception of the mercury-driven CRU), with the least stringent criteria (e.g., specific weight) of all SNAP systems contemplated. In addition, it has received the most development work over the longest period of time. While some limited testing of small components is possible by hitch-hiking on other satellite systems on a non-interference basis, it would be difficult to find enough space to test a full non-nuclear system on this basis. Furthermore, non-nuclear testing of a complete power conversion system with a mockup nuclear heat source would be a problem since the amount of payload remaining for fuel and oxidizer would greatly limit the life of the test. In essence, even for system testing in space, a nuclear reactor is the only heat source capable of furnishing adequate on-board heat energy.

The weight (1470 pounds) and radiator area (120 square feet) of a 3 KWe SNAP-2/10A turboelectric system are comfortably within the capability of the Atlas-Agena booster-satellite system to place in a reasonably safe orbit. The system embodies representative components found in all the more complex concepts which are based on the Rankine cycle. A successful flight test would demonstrate that startup in orbit of a two loop system is possible, that shield-design theory is correct, that boiling and condensing in zero gravity can be handled, etc. When larger booster-satellite combinations are available, modular application of this system can be expected to meet power needs up to thirty kilowatts (using the SNAP-8 reactor at 450 KWt). The possibility of conducting this useful experiment with a larger system would be handicapped by the availability of a vehicle with sufficient payload capacity. Currently, the Atlas-Agena has proven reliability and can be purchased at a nominal sum when compared to other new and yet unproven systems.

If SNAP-2/10A cannot be made to operate successfully, there is little chance that the more complicated systems would work. Every effort should be exerted to insure that the flight demonstration tests, when conducted, do not fail through lack of adequate preparation or a realistic test schedule.

The amount of development work and ground testing being expended on the SNAP-10A system should suffice to insure reasonable confidence in its feasibility. The time and effort required to substantially increase confidence beyond the goals set by the contractor do not appear warranted since several variables vital to the success of the demonstration cannot be verified precisely in ground tests. These include orbital startup, zero-gravity effects, effectiveness of shadow shield design, and self-welding in space. On the other hand, an adequate number of flight tests should be scheduled to provide an acceptable probability of success. Available data on failure modes from each shot could be factored into succeeding shots. These flight tests would cost in the neighborhood of $15-20 million each. Should the goals assigned to this series of tests be reached in an early flight, the succeeding flight tests could be either cancelled or reoriented to more advanced goals.

If SNAP-2/10A systems were flight tested successfully, there would be available a reactor heat source and two power conversion systems with demonstrated feasibilty in space. Successful operation of the Rankine cycle in space is particularly important since the AEC is relying on this cycle in its advanced reactor programs. Should the Rankine power conversion system prove infeasible, a major change to another power conversion cycle may be necessary. It is possible that too much emphasis is being placed on the Rankine cycle before feasibility demonstration has been made in actual flight. Work on other power conversion modes (thermionics, Brayton, supercritical, MFM) should be continued in parallel with Rankine cycle development until the Rankine cycle demonstration is accomplished. Work on the most promising of the alternate cycles should be continued, providing a definite improvement over the Rankine cycle can be shown to exist.

SNAP-8 Program

A. Technical Review

This system is being developed jointly by the Atomic Energy

Commission and the National Aeronautics and Space Administration. The AEC is responsible for developing the nuclear system; NASA is responsible for developing the power conversion system and its integration into an operating electric system. The SNAP-8 reactor concept is based on the technology developed for the SNAP-2/10A reactor systems. Table 3 presents design objectives of the SNAP-8 reactor.

TABLE 3

Design Objectives - SNAP-8 System

Electric Power	35 KWe minimum
Thermal Power	300-600 KW
Reactor outlet temperature	1300°F
Reactor inlet temperature	1100°F
Control	Active
Life	10,000 hours
Power conversion system	4-loop Rankine
Specific weight	175 lb/KWe
Power density	75-150 watts/cc

The most significant design changes are the increase in reactor outlet temperature to 1300°F and an increase in power density over SNAP-2/10A conditions. As a result, the hydrogen retention capabilities of the barriers developed for SNAP-2/10A are not adequate and development of more effective barriers is under way. Swelling of irradiated fuel indicates that increase of the fuel-to-cladding gap width is necessary to cope with this problem. Evaluation of this solution is under way. Collection of hydrogen gas in the condenser may also prove to be a problem.

Another problem associated with the higher temperatures involved in SNAP-8 is the possibility of mass transfer in the primary coolant loop. This is currently under study by NASA.

The problems inherent in an intermittently active control system are also present in the SNAP-8 design. In addition to binding problems mentioned earlier, the control system depends on accurately sensing reactor outlet temperature. Reliability and accuracy of temperature sensors in space and reactor environment for periods of a year remains to be demonstrated. Based on difficulties encountered in ground tests, this may be troublesome.

The current shield design does not adequately protect the payload due to the location of the NaK pipes and electrical conductors on the outer surface of the shield. In addition, permissible radiation doses to the payload have been reduced from 10^7 to 10^6 rad/yr. Redesign of the shield will be necessary.

NASA is developing the power conversion system for SNAP-8. They have departed from the combined rotating unit concept in an attempt to solve bearing lubrication and mass transfer problems. The current working cycle loop under development consists of four loops: 1) a NaK primary loop through the reactor and boiler operating at 1100-1300^{o}F; 2) a mercury two-phase loop through the boiler, turbine, and condenser operating at 1250-680^{o}F (200^{o} superheat); 3) a main NaK single-phase heat rejection loop through the condenser and the radiator operating at 665-497^{o}F; and 4) an organic cooling loop for the electrical components operating at 250-210^{o}F and bearings. A unique feature of the system is the four-stage axial-flow turbogenerator set which consists of an over-hung turbine coupled to the alternator by means of a flexible coupling and a spline. Two sets of rolling-element bearings are used for each component. The advantages cited for this system are the operation of the turbogenerator bearings in "oil" at a relatively slow-speed (12,000 RPM), the ability to test components separately and to make changes in separate components.

This system is expected to have a specific weight of about 175 lb/KWe which may restrict the use of the SNAP-8 electrical generating system for use with electric propulsion but it may still be usable for auxiliary power.

The SNAP-8 program is in its early stages with the bulk of its power conversion system development work still in the future. Work to date indicates that much effort must still be expended, particularly in the power conversion system to achieve presently set goals. Consequently, it is too early to discuss system growth capability except in broad generalities. The coupling of the SNAP-8 reactor with [illegible] combined rotating units has been mentioned earlier. Uprating of system performance could be achieved in three ways: increasing reactor outlet temperature while holding power constant (reduction in overall weight); increasing power level while holding temperature constant (simple increase in power); and increasing both power and outlet temperature. Marginal increases would merely accentuate current development problems without significantly improving performance. Major changes to affect power improvements would require complete redesign of the system and would raise the question whether this route or an alternate is the more fruitful.

B. Discussion

The SNAP-8 Experimental Reactor (S8ER) has been brought to power and although not using the final design fuel element, it will be expected to verify a number of uncertainties as to the fuel element and corrosion problems. The SNAP-8 Developmental Reactor Mock-up (S8DRM-1) will develop data on lifetime and reliability of the core and flight test hardware under non-nuclear conditions but at temperature. The reactor to be used in the SNAP-8 Developmental System (S8DS-1) should be built and operated without the power conversion system to develop fully the SNAP-8 reactor heat source for 10,000 hour use.

In view of NASA's continued interest in the SNAP 8 program and their development of the power conversion system, close liaison should continue between the AEC and NASA so that any feedback from the power conversion system development can be reflected in the reactor design with a minimum of delay.

Extensive ground testing of the system is planned before a flight test is undertaken.

The Lithium Cooled Reactor Experiment (LCRE)

A. Technical Review

The LCRE program is an outgrowth of the Aircraft Nuclear Propulsion (ANP) program. In 1961 the decision was made to modify the PWAR-11C test reactor to reduce its size and to increase operating life of the reactor from 1000 hours to 10,000 hours with the objectives of:

a) Operating a high performance lithium cooled reactor system at bulk-outlet temperatures up to 2000°F;

b) obtaining physics and control parameter data for a high-energy spectrum reactor;

c) obtaining engineering performance data on a high performance reactor;

d) confirming physics and engineering design of the reactor systems by operating experience and post-test examination.

Exclusive of design changes dictated by the revised objectives, the basic characteristics of the ANP reactor were retained in order to take advantage of the wealth of previous experience gained during the course of the ANP program. Thus, UO_2-BeO was retained as the fuel and lithium as the coolant. The main changes in LCRE as opposed to the ANP reactor were the following: the volume percent of UO_2 in the UO_2-BeO fuel matrix was raised; the power density was reduced; the core size was reduced; and a void was provided in each fuel element.

It appeared that LCRE was a modest extrapolation of the ANP reactor design and that most data obtained in the ANP program would be applicable to LCRE. All that would be required was a follow-on program tailored to LCRE operating conditions demonstrating the lifetime at the bulk outlet temperature. A program to investigate fuel cladding and coolant effects at LCRE operating conditions was therefore undertaken, including in-pile experiments. As a result of these tests and tests undertaken in other laboratories, several serious problems were discovered which reduced the anticipated performance of the reactor.

In recognition of these problems and the high cost of completing the experiment, it has been decided to cancel construction of the LCRE.

The SNAP-50 Program

A. Technical Review

The objective of the SNAP-50 program is the development and demonstration of an advanced Rankine cycle reactor-powered system capable of producing power in the range of 300-1,000 KWe at an unshielded specific weight of 10-20 lbs/KWe. A compact lithium-cooled refractory-alloy reactor operating at 2000°F bulk outlet temperature coupled to a boiling-potassium turbo-generator has been chosen as the design to be developed for this purpose. The four steps originally planned to achieve this goal are:

a) Construction and operation of the LCRE.

b) Development and testing of a prototype SNAP-50 reactor and primary loop components known as Development Reactor No. 1 (DR-1).

c) Development and testing of prototype power conversion components.

d) Construction and ground testing a prototype plant combining the DR-1 and power conversion systems.

The decision to discontinue the LCRE program is covered in the preceding section.

Development of DR-1 was begun in FY 1962 and now includes system study, reactor and primary loop design, fuel and structural materials development, and primary pump and boiler development.

A comparable effort to solve the problems related to the energy conversion system has not been started. While the development of the reactor and its loop will be difficult, the development of the turbine, generator, pumps, bearings, heat exchangers, radiator, instrumentation, etc., will also present problems of equal magnitude.

There has been a limited examination of the trade-offs between power, achievable weight, and life of the total system using such parameters as operating temperature and reactor-fuel dilution. Likewise, certain factors such as the structural support for the system have not been adequately investigated. Prior to starting final design of a reactor system, the iterative process of supplying the best information available concerning the known physical properties of the materials and performance of any components into a preliminary design will serve to guide both materials work and physical layout.

Achievement of the SNAP-50 specific weight goals at the low end of the power range, i.e., 300 KWe, will be very difficult because the reactor-shield combination represents a large percentage of the overall weight, which cannot be reduced significantly because of reactor-criticality and heat-transfer limitations. The weight savings, therefore, must be gleaned from the power conversion components of which the radiator is probably the heaviest. Operation at higher temperatures and the use of refractory materials would serve to reduce the size and weight of this component, however, such materials are not yet developed.

At the upper end of the power range, i.e., 1,000 KWe, the weight of the reactor-shield combination becomes a smaller percentage of the overall weight, and the radiator, because of its large area, becomes a major weight factor. Since every pound per kilowatt saved in the radiator results in a large weight savings in the total system, there is strong incentive for high-temperature operation of the system.

Considerable variance exists in the estimates of a number of contractors regarding the specific weight of the radiator. Some tend to omit the auxiliary radiator for cooling various temperature limited components and the required supporting structure which can account for a large portion of the weight attributable to heat rejection.

Inasmuch as the weight of the radiator accounts for a large portion of the weight of the system, a careful study of the possible problems and solutions is in order. Development effort should be started as soon as possible. It is quite possible that the weights of the radiator may dictate whether or not is is possible to achieve the ultimate goal of low specific weight.

Materials

A preliminary design of SNAP-50 was based on a reactor fuel composed of uranium-carbide. Preliminary work on other fuels such as uranium-nitride and uranium-dioxide is also underway. Uranium nitride has many attributes that make it of interest as a fuel material. It is quite similar to UC in most properties but appears measurably superior to UC in uranium density, melting point, and possibly high-temperature thermal conductivity. Current investigations are not fully in agreement on these properties but recent results are compared in Table 4. The nitride also appears, on the basis of fragmentary irradiation data, to be somewhat superior to UC in retention of fission gases. One property of UN which has not been eliminated as a possible cause of trouble is its chemical stability. It has a measurable dissociation pressure at high temperatures (5×10^{-6} to 1×10^{-5} atmospheres at 3000°F).

TABLE 4

Properties of Fuel Materials

	UO_2	UC	UN
Melting Point, °F	5070	4350	4660 to 5230
Uranium Density, gm U/cc	9.66	12.97	13.52
Thermal Conductivity, BTU/hrs-ft-°F (1000-2000°F range)	1.2 to 1.7	13.3	11.9(1470°F)*

*Also reported to be higher than UC above 1300°F.

Compared to the carbide and nitride, UO_2 has been exhaustively studied. The apparent attractiveness of the other compounds may be based in part on a lack of knowledge. However, there are three well established attributes of UO_2 which are unfavorable. The density of uranium oxide is low which will increase core size and shield weight; its thermal conductivity is low which raises centerline temperatures and increases the rate of fission gas release; and it is chemically reduced by liquid lithium in the event of a cladding failure. Free energy relations indicate that it should not suffer reduction in liquid sodium or potassium. Although there have been instances reported of attack by sodium, these may have been due to impurities. In its favor is the fact that it will not react with any of the refractory metals so far considered. While the limitations of UO_2 noted above may ultimately rule it out of very advanced high power density reactors, it may prove to be a more readily achievable solution to the design problem of intermediate power density reactors.

Lithium has been selected as the primary-loop coolant because of its demonstrated heat transfer capabilities, low vapor-pressure, and low pumping-power. A large amount of successful loop experience tends to verify this material as the best selection. If UO_2 is used as a fuel, emphasis must be placed on developing an impervious cladding since lithium readily attacks UO_2, forming free uranium. If this is not feasible, another coolant must be found. On the other hand, lithium does not attack uranium-carbide. Less is known about the effect of lithium on uranium-nitride.

Primary Loop Pump

A design and experimental program to develop this component is underway. The emphasis on this high temperature component is in order since the LCRE pump cannot be modified for SNAP-50.

Boiler

Test boilers for parametric work have been built and are being tested. A multi-tube boiler system is also being designed. The operation of LCRE heat exchangers would not provide data applicable to the DR-1 boiler development since they are not boilers and do not operate at SNAP-50 conditions.

Power Conversion System

The Rankine cycle has been selected for the heat-to-electrical energy conversion process for SNAP-50. Each 300 KWe system contains a turbo-generator-pump unit operating on potassium vapor which rejects its waste heat to four individual heat exchangers which in turn reject heat to four individual main radiator loops cooled by pumped lithium.

In addition to the four main radiator segments, each 300 KWe system contains an auxiliary loop with its radiator and pump. This potassium loop cools the generator stator and rotor, primary pump stator and rotor, radiator pumps, transformer, and other components.

The reliability of the complex SNAP-50 system is of concern. For example, a statistical analysis of data on forced outage experience with 187 commercial turbogenerator units in the TVA system has shown that if a unit is started up and checked out satisfactorily, there is only a 4% probability that it can be operated for a year without a forced outage. The failures that occur are attributable mainly to wheel rubbing, exciter brush failures, throttle valve sticking, and bearings. Motor driven pumps are still unreliable and cavitation-induced erosion over long periods of operation induces a variety of impeller and vane failures. Figure 1 depicts the typical experience with commercial rotating equipment and goals of the more ambitious AEC programs. The SNAP-50 program falls in the area that is beyond any prior experience.

The great complexity of automatically and remotely starting this multi-unit system in orbit and operating reliably for 10,000 hours continuously at conditions approaching the limits of the materials will be a formidable task.

B. Discussion

The goal of 10-20 lbs/KWe for systems in the megawatt category is mainly applicable to the manned Mars missions and Jupiter capture-missions. This low specific weight system has been established as a DOD/NASA/AEC joint objective. Any specific weight over 10-20 lbs/KWe places an inordinately high reliability and life specification on the power unit since a longer transport time is required. A high-temperature system results in light weight and shorter transport time, hence a lower and more favorable endurance requirement.

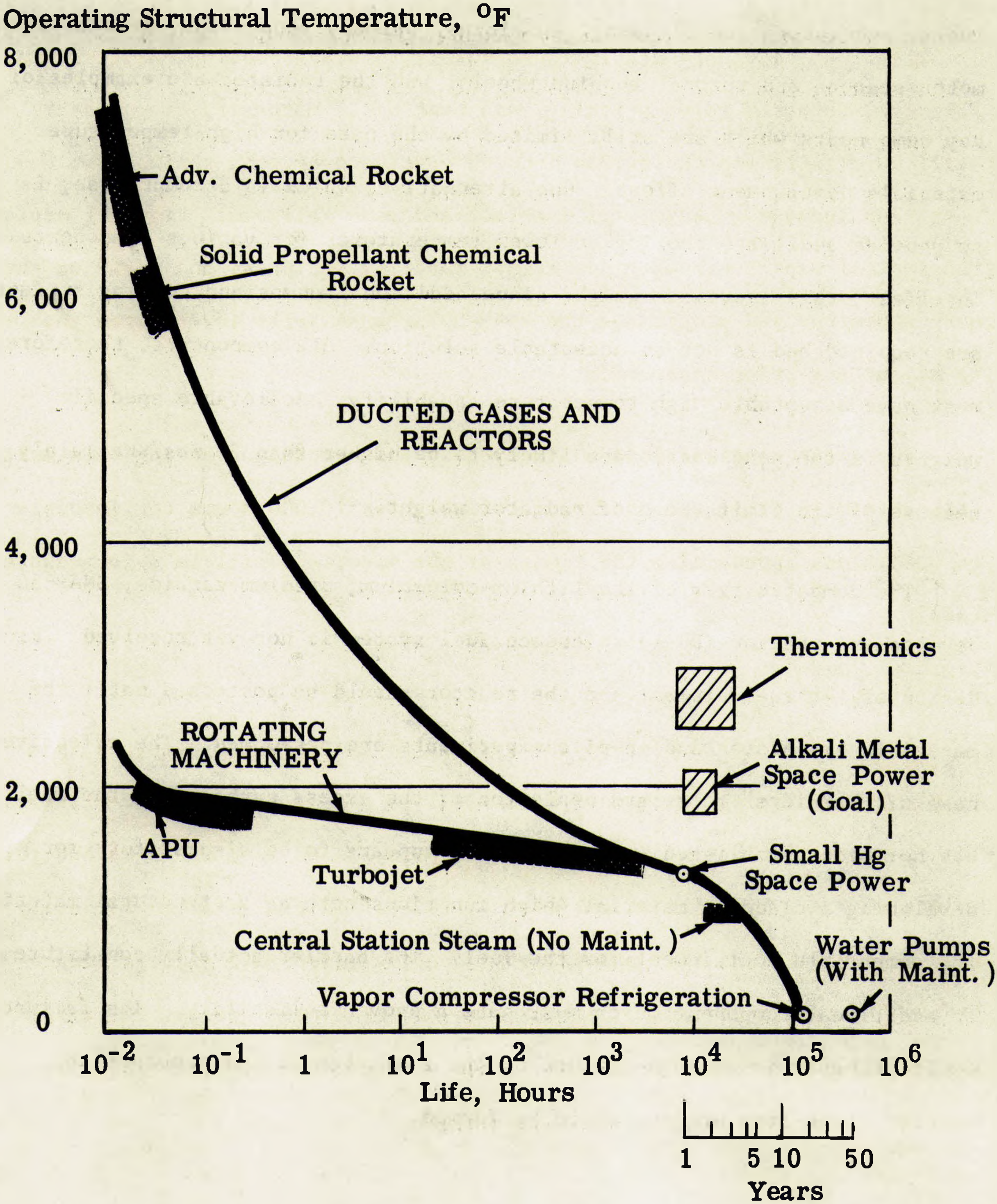

Figure 1

MAXIMUM OPERATING TEMPERATURE vs LIFE FOR POWER EQUIPMENT

Achievement of the 10-20 lbs/KWe goal in the SNAP-50 program will depend primarily on the development of high temperature materials. Reactor fuels, reflectors and cladding, shielding, primary loop pumps, generator and motor stators and rotors, turbine wheels, and the radiator are examples of key components which are still limited by the need for high-temperature materials development effort. One alternative, which is a compromise, is to provide auxiliary cooling at lower temperatures for various components. In effect, this increases weight since additional pumps and cooling surfaces are required, and is not an acceptable solution. All components, therefore, must have acceptable high temperature capability. Achievable specific weights in the next decade are likely to be higher than 20 lbs/KWe mainly because of the limitations of radiator weight.

The compatibility of the lithium-columbium, uranium-carbide, SNAP-50 development reactor (DR-1) reference fuel system is not yet resolved. Final design of the fuel element and the reactor should be postponed until the materials are proven and in-pile experiments are performed. The effectiveness of "barriers" to retard depletion of the excess carbon from the fuel has not been established. In fact, this appears to be a substitute for developing a cladding material which functions both as a structural material and compatible containment for the fuel. The barrier actually constitutes an additional component which must have a proven reliability. Its failure would probably constitute failure of the fuel element and probably the reactor since free uranium would be formed.

The Advanced High Temperature Materials Program at CANEL covers a spectrum of materials investigations which largely constitutes an effort in support of SNAP-50. The coverage of this program could advantageously be enlarged and closely allied with the SNAP-50 effort. It is also advisable to seek further assistance from other laboratories where high temperature materials work is in progress. The specialized capabilities of NASA and the DOD in such areas as power conversion components are also being brought to bear on these problems. Full advantage of their advance work should be factored into the SNAP-50 effort.

This high temperature materials work coupled with the development and operation of a succession of complex ground demonstration test-rigs, as well as design and check-out of new facilities, indicate that the specific weight goal is probably not achievable in a ground demonstration unit for at least ten years or more. After the initial period of ground demonstration, flight testing, and ultimately the development for a specific mission with required high reliability will add another 5 or 10 years to the effort.

Budget levels for the program cannot be accurately predicted; however, it is probable that the following overall costs are not unrealistic:

(10 years)	Ground Demonstration	\$ 600 - \$ 800 million
(5 years)	Flight Demonstration	300 - 400
(2 years)	Operational Development	100 - 200
(Concurrent)	Reliability Development	300 - 400
	Total	\$1,300 - \$1,800 million

In the course of this study, the need for a high temperature fast flux irradiation facility has become evident. Such a facility is needed to pursue the materials research required to develop SNAP-50 and other fast space reactor systems. It is understood that a similar need has existed in the fast breeder reactor program for a number of years and an examination of existing facilities has not discovered any that would fully meet their requirements. The feasibility and desirability of constructing a high temperature fast-flux reactor suitable for use by both the fast breeder reactor program and the advanced space reactor program should be explored. A facility capable of providing fast fluxes is required in the materials program if the advanced space reactor program is to proceed in an expeditious manner.

The long range character of requirements and the state of the technology indicate that a well defined system-oriented SNAP-50 program is premature. As generally outlined above, the program should address itself primarily to development of high temperature advanced materials including the nuclear fuel and development of key components with due consideration to eventual system integration.

Summary of Reactor SNAP System Characteristics

Table 5 presents a summary of some of the important technical characteristics of space reactor systems. The LCRE, though not a space reactor system, is included because of its connection with the SNAP-50 program.

TABLE 5

Technical Characteristics of SNAP Reactor Systems

SYSTEM	REACTOR TYPE	POWER KWe	FUEL ELEMENT				COOLANT			RADIATOR CONDENSER			SYSTEM SPECIFIC POWER	POWER CONVERSION SYSTEM				
			Material	Power Dens. Watts/cc	Cladding	Max.Temp. Hot Spot °F	Fluid	Average Out °F	Hot Channel °F	Material	Area	Weight	Estimated $/KWe	Type	Working Fluid	Temperature In °F	Temperature Out °F	E
10A	Thermal	0.5 (2)	UZrH	12.7	Hastelloy	1100	NaK	1010	1030	SS-AL	62.5	~ 150[a]	2000 (600)	Thermo Elec.	NaK	987	882	1.6
2[b]	Thermal	3 (10)	UZrH	21.8	Hastelloy	1250	NaK	1200	1220	SS-Cu	118	225	520 (250)	Rankine	Hg	1160	625	5.4
8	Thermal	35 (100)	UZrH	75-150	Hastelloy	1580	NaK	1300	1480	SS-AL	1400	1900	~ 175 (50)	Rankine	Hg	1250	680	8.8
LCRE[c]	Fast	N.A.	UO_2BeO			2530	Li	~2000		N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
50[d]	Fast	300 (1200)	UC			*	Li	~ 2000	*	*	*	*		Rankine	K			

a/ Entire power conversion system.
b/ Development of this specific system terminated.
c/ Terminated.
d/ Entire system in early design stages - characteristics tentative.

* Not determined.
N.A. Not applicable.
(-) Indicates potential.

III Evaluation of Alternate Approaches

The Boiling Potassium Reactor Experiment

For the past two years, a small reactor program at Oak Ridge has been underway to investigate the use of state-of-the-art materials and to bridge the gap between SNAP-8 and SNAP-50 system objectives. While the reactor would be limited in operating temperature ($\sim 1500^{\circ}F$), it could be made small in size at power levels of about 150 KWe. Some improvement in specific weight is achievable at higher power levels; however, refractory metals would be needed to permit operation at higher temperatures.

Some progress has been made in the initial stages of this concept and it appears to be a promising approach. Table 6 shows the relative parameters of SNAP-8, SNAP-50, and the boiling potassium experiment.

TABLE 6

Relative Design Parameters

	SNAP-8	Boiling K Reactor	SNAP-50
Power KWe	35(100)*	140(400)	300(1200)
Reactor Outlet, $^{\circ}F$	1300	$\sim$1500	$\sim$2000
Radiator Temp., $^{\circ}F$	665-497	1050	1156-1006
Fuel	UZrH	UO_2	UC
Reactor Coolant	NaK	K	Li
Cycle Fluid	Hg	K	K
Est. Specific Wt., lbs/KWe	175(50)		

*(-) Indicates estimated potential limit.

The initial experiment with the boiling potassium reactor concept is being carried out to ascertain the feasibility of a simple, direct-boiling, single-loop system. Uranium dioxide fuel, however, can be used at higher temperatures in an indirect system if a structural material such as columbium-zirconium is employed.

The Brayton Gas Cycle

The gas cycle is simpler than the Rankine cycle in that the working fluid is in the vapor phase throughout the system. No free liquid surfaces exist in the system which require stabilization by surface tension, centrifugal forces, or other methods. Also, the use of an inert gas can simplify materials compatibility problems. The gas cycle, however, is hampered by lower heat transfer capability and high compressor work. This results in a higher specific weight than the Rankine cycle.

The large work input required for the compression process, which increases rapidly with temperature, makes the gas cycle sensitive to compressor-inlet temperature. Net work and overall cycle efficiency drop off rapidly with increasing compressor inlet temperature so that any practical plant based on current reactor technology must maintain the compressor inlet temperature below about 150°F.

Certain gas-cycle machinery contractors indicate that there have been improvements in component efficiencies, heat exchanger compactness, high speed alternators, and gas bearings over the last few years. These factors, coupled with the use of a regenerated cycle, indicate that some reconsideration should be given to the low power Brayton cycle.

Studies have been made of the applicability of the gas-cycle as a substitute for the SNAP-2 and SNAP-8 Rankine cycle secondary systems. The radiator areas for both systems were about 50% greater even though optimistic gas-cycle component parameters were used. For these lower power systems, however, a radiator area of 50-60 ft^2/KWe (typical for gas-cycle) could be handled with current boosters. Larger power systems using the gas cycle will result in large radiator areas, even at high heat-source temperatures.

The trade-offs between gas cycle and the Rankine cycle involve the advantages of simpler fluid circulation problems, simpler rotating components, and possibly fewer corrosion problems enhancing reliability prospects. These must be weighed against the penalty of achieving higher fuel operating temperatures and accepting larger radiator areas and weights.

Before proceeding with the development of any gas-cooled reactor, a thorough system analysis should be made to identify the advantages as well as the problem areas. A reactor of this type may have merit either as a direct Brayton cycle system or in conjunction with a Rankine secondary power conversion system. If the potential of the system is attractive, then the solution of individual materials problems should precede component development. In this connection, reference is made to the development of fuel material such as UO_2 (particles or coated-particles) dispersed in refractory metals such as tungsten for use in a fast reactor for space applications.

There is little doubt that a demonstration gas cycle system can be built using the primary loop of a sodium cooled reactor, such as SNAP-8. Such a system would provide technical verification of the merits of the gas cycle for low power levels at reasonable cost. In summary, the expected simplicity and inherent reliability of this concept warrants continued work.

Thermionic Energy Conversion

The AEC is sponsoring research and development in the field of thermionics to explore the potential advantages offered by reactor-powered thermionic conversion systems for space use. Both DOD and NASA also are sponsoring work in the area of thermionic conversion. Two general types of reactor thermionic systems are under study. These are "in-core," where the thermionic diodes are built into the fuel element and operate in the reactor radiation environment, and "out-of-core" where the thermionic converters are located outside the reactor and are closely integrated with the heat rejection system. Although the AEC's program concentrates on the in-pile concept, each system has its own particular advantages and problems.

In-Core Thermionic Systems

The major advantage expected of the in-pile concept is the potential of achieving a compact, low specific-weight system. Low specific weight results from the use of a compact reactor as the heat source, high heat flux and current density in the thermionic diode, and high heat rejection temperatures. Exclusive of the need for a pump to circulate liquid-metal (which may be accomplished electro-magnetically), there are no other moving parts. The concept, thus, offers the characteristics of inherent reliability that are afforded by static systems.

The in-core thermionic converter offers the advantage of being able to operate the emitter at the highest temperature available in the system. Feasible emitter temperatures might exceed 3000^{o}F in reactor systems. The emitting surface of the cathode is usually designed as the exterior of the fuel element cladding. The collecting surface of the anode is a concentric-cylinder spaced 5 to 20 mils from the emitter, and is electrically insulated from the outer structure and coolant channels. The coolant, which operates within current technology capabilities, passes over the outer surface of the collector and transfers the reject heat to the radiator.

The placement of the converters inside the reactor presents many problems which arise from operation in an irradiation environment and the requirement placed upon the converter of performing as both an energy converter and a reactor fuel element. Unfortunately, the emitter materials that have the highest conversion efficiencies also have high neutron absorption cross-sections and/or poor structural properties at operating temperature. Rhenium and molybdenum are examples of such materials. Emitter materials must also be compatible with the fuel material. At the present time tungsten appears to be the most pupular choice of emitter material although it is not the best emitter. It offers, however, an acceptable compromise in properties for high-temperature fast reactors.

An additional problem involves the fission gas generated in the fuel element. At the high fuel temperatures required for them ionic operation, fission gas retention is not very good and burnup may be limited.

Ordinarily, in simple fuel-element designs the gas could be vented into a void-space with some leakage into the coolant being tolerable. Venting fission gases into the diode space, however, may greatly alter the efficiency of operation of the converter.

Single diodes have been operated at efficiencies between 10 and 15% at emitter temperatures of 1700 to 2000°C. It is possible that the non-uniform power distribution in the reactor may reduce appreciably the diode efficiency. Unless this problem is minimized, the overall weight advantage of the in-pile system may not be realized.

Many other problems exist, the magnitude and difficulty of which cannot be assessed at this early stage. These relate to the operation, control, and life of the reactor with the complex, multi-material fuel elements forming the core; and the life of the thermionic fuel element with its multitude of connectors, small vents and passages, insulators, etc.

The amount of in-core testing of the diodes performed has been limited, Operation for a few hundred hours has been achieved. The problems being studied under the AEC-sponsored effort are choice of fuel form and thermionic materials, fission product venting or containment without swelling of the fuel element, and testing of thermionic converter modules in reactors.

This program should remain in the basic component development stage until all the problems associated with the concept are thoroughly understood.

As promising combinations of fuel, diodes, and heat rejection systems are developed, it is advisable to test modular systems in-pile to further identify problems peculiar to system operation. Wherever possible these tests should be carried out in fast-flux reactor test facilities to simulate future systems.

Out-of-Core Systems

Out-of-core systems avoid most of the problems typical of the in-core concept and also offer the flexibility of developing the converter system independent of the reactor heat source. This system, however, will have inherently higher specific weights than the in-pile system. The development of thermionic modules should be simpler than the in-pile converters since materials available are not restricted by considerations of reactor environment and the operating temperatures are considerably lower. A major problem centers around the need for a high temperature (2400-2500°F) liquid metal loop to transfer the reactor heat to the thermionic emitters located in a heat exchanger or the radiator. In order to achieve the potential of this type of system, liquid metal operating temperatures must be raised from present experience at about 1800°F to at least 2500°F. System efficiencies up to 10% have been estimated at these temperatures.

Little work is being done on out-of-core systems at the present time because of the need for development of a 2500°F pumped-loop and associated equipment. The development of the pump would be a major task. An electro-magnetic pump is impractical at these temperatures; therefore, a dynamic pump will be required. Refractory metals will be required for the loop increasing the weight of the system substantially. An added complication is the requirement for applications of a thin layer of electrical insulating material between the refractory metal loop and the emitter. This insulating material must operate at very high temperature (2400-2500°F) and not unduly restrict the transfer of heat. The low emitter-temperatures available at the present level of liquid metal loop technology would yield a system efficiency below 5% and are, therefore, unattractive.

Liquid metal technology should be extended as rapidly as possible since the problem may not be as formidable as anticipated and since it represents the major obstacle to out-of-core systems. The results of this work would be applicable to all high temperature power systems. Also, the development of materials for in-pile converters is directly applicable to out-of-pile converters. In fact, some materials which are unsuitable for in-pile use may be attractive for out-of-pile operation.

Other Advanced Concepts

A number of new power conversion schemes are being examined in various companies and laboratories around the country. Two of these appear to have sufficient merit to warrant further investigation as to their feasibility and potential for space uses.

One of these schemes is based on the magneto-hydrodynamic principle of energy conversion and is being pursued by several organizations. The principles involved in the various approaches are similar and can be characterized by reference to a concept which is called the Bubble Flow Magneto Fluid Mechanic System (MFM). In this system, a lithium cooled reactor operating at 2000°F circulates lithium into which liquid potassium is introduced from a secondary potassium loop. The potassium enters the lithium at a nozzle and is vaporized. The potassium vapor expands in the lithium stream at it passes through a magnetic field creating useful power. After leaving the generator, the stream is passed through a separator and the lithium is returned to the reactor while the potassium is directed to a condenser.

Liquid metal MFM systems as described above are attractive in that they have few moving components. On the other hand, research in this field is in its infancy and the problems associated with it are ill-defined. This system appears attractive at power levels of 1 MWe or greater and is, therefore, an alternative for the SNAP-50 Rankine cycle power conversion system.

Another power conversion system which is in the early conceptual stages is the supercritical cycle which operates entirely in the super-critical region of the working fluid. It has the advantages of the Brayton cycle in that is is a single phase system with the ability to regenerate most of the reject heat from the turbine without the inefficiency introduced by compressing the gas as in the Brayton cycle. In this cycle, the supercritical fluid is cooled to just below the critical temperature so that a dense, incompressible fluid is pumped at maximum efficiency. Efficiencies on the order of 60% are claimed for this cycle.

This scheme has not yet progressed beyond the theoretical and initial investigation demonstration stages and little is known about the problems associated with it. A working model has operated using CO_2 as the working fluid which is not practical for space purposes, since pumping is accomplished at 35-75^oF. In fact, working fluids have not been identified as yet nor have the problems associated with operating at very high pressures in space been explored.

As is evident from the above, both the MFM and the supercritical energy conversion schemes are in their earliest stages and cannot be seriously considered for the next decade. Nevertheless, the sole dependence of the SNAP 50 program on a complex multi-component Rankine cycle system counsels that alternative systems should be reviewed in the event that the Rankine cycle does not prove successful.

Plutonium fueled fast reactors for space have been investigated, and appear to have attractive potential for compact, low specific weight systems with long reactivity life and/or lower fuel inventories due to the favorable nuclear characteristics of plutonium in a fast spectrum. In light of the extended time scale for potential requirements of high-power low specific weight systems, the relatively less advanced state of development of plutonium fuels should not militate against their being given due consideration. It is believed that further exploration of their potential for space application is well warranted.

SNAP ISOTOPE PROGRAM

I Requirements and Potential Applications for Isotopic SNAP

Recent compilations by NASA and DOD of probable space electrical auxiliary power needs, regardless of the type of power generator to be employed, i.e., solar cell, isotopic, or battery, for unmanned satellites and probes during the four years, 1964-67, indicate that around 20,000 electrical watts in total might be required. The details are given in Table 7. Mission schedules beyond 1967 are a matter of speculation; however, a very rough estimate is that the total annual requirement for power generators of less than one kilowatt capacity will probably be in excess of 5,000 watts/year.

Of the various space missions, several are of a system character: the weather satellite system (Tiros, Nimbus), the communications satellite system (Telstar, Relay, and Syncom), the military communications satellite system, and the Navy navigational satellite system. Such systems are usually maintained by periodic replacement of orbiting satellites which have either failed or reached the end of their useful life. Satellites making up these four systems account for about one-third of the total electric power requirements during the 1964-67 four year period.

Isotopic power sources will be used in some of the space missions shown in Table 7, but the total number of such applications is unknown at this time. Isotopic power generators have been developed for the Navy navigational satellites (SNAP 9A), the Surveyor Lander (SNAP-11), and the Interplanetary

Monitoring Probe (IMP generators). Whether the latter two applications will take place is yet uncertain. Work on several designs of a 25-50 eW strontium generator suitable for a medium altitude military communication satellite has been initiated. NASA has inquired into the feasibility of using isotopic power on the orbiting astronomical observatories and Nimbus weather satellites. Other missions which could quite conceivably employ radioisotope thermoelectric generators are the Anna Geodetic Satellite, Surveyor Orbiter, and the communication satellites Telstar, Relay, and Syncom. Radioisotope thermoelectric generators could be used on geophysical and biophysical type satellites if they do not interfere with the various on-board radiation measuring experiments. The solar observatories are sun oriented and therefore will most likely use oriented solar cell systems.

Auxiliary electric power needs for manned space missions have not been included in this compilation as it was felt that they would be definitely scheduled by firm requirements if the user agencies desired to use isotope generators in any of these flights.

Potential large scale terrestrial applications of isotopic power sources (Table 8) are under consideration and could require more than 20,000 electrical watts of generator power for the 1964-67 four year period.

TABLE 7

SPACE ELECTRIC POWER REQUIREMENTS

TENTATIVE FLIGHT SCHEDULE

	Approx. Power Steady Load Electrical Watts	Number of Satellites per Year 1964	1965	1966	1967
SCIENTIFIC SATELLITES & PROBES					
1. Astronomy					
Orbiting Astronomical Observatories	500	-	1	2	1
2. Solar Physics					
Orbiting Solar Observatories	25	2	1	2	1
Advanced OSO	15-50	-	-	-	2
3. Geophysics & Geodesy					
Orbiting Geophysical Observatories	500	1	3	1	3
Explorers	15-50	1	3	1	2
Monitors - Interplanetary Monitoring Probe	40	1	3	2	2
International	15-50	7	5	6	4
Anna Geodetic Satellite	50	-	3	2	1
4. Biophysics					
Biological Satellites	25	-	1	4	1
5. Lunar Science					
Ranger - Lunar Impact	150-190	4	-	-	-
Surveyor Lander	15-25*	-	5	2	-
Surveyor Orbiter	125	-	-	4	3
6. Planetary and Interplanetary Science					
Mariner (Mars & Venus)	150-250	2	-	4	2
Pioneer	5-100	-	3	3	1

*Power when landed, 100 eW enroute.

TABLE 7 - Continued

	Power (eW)	Number of Satellites per Year 1964	1965	1966	1967
SATELLITE APPLICATIONS - NONDEFENSE					
1. Meteorology					
Tiros	25-50	1	-	-	-
Nimbus	140-250	1	1	1	1
2. Communications Satellites					
Telstar	60	1	12	10	8
Relay	50	2	-	-	-
Syncom	25-100	1	1	2	-
SATELLITE APPLICATIONS - MILITARY DEFENSE					
1. Communications Satellites					
Medium Altitude	25				
Syncom	100				
2. Navy Navigational Satellites	25				

TABLE 8

POTENTIAL TERRESTRIAL APPLICATIONS OF ISOTOPIC SNAP

	Approx. Generator Power Electrical Watts	Potential 1964-67 Requirements Number of Generators	Total Electrical Watts
Military Defense Applications			
1. Navigational Aids - Navy	10		
2. Anti-submarine Warfare Coastal Surveillance - Navy	150		
3. Oceanographic and Weather Monitors - ASW Support - Navy	20		
4. Dormant Missile System - Air Force	100		
Government and Civilian Nondefense Applications			
5. Weather Stations - Interagency	20-60	50	1,000-3,000
6. Navigational Aids			
Alaskan and Aleutian Shore Lights - Coast Guard	5-15	70	350-1,050
Buoys - Alaskan Waters - Coast Guard	10	70	700
Gulf of Mexico Oil Wells - Civilian	50	100	5,000
Beacons - Coast Guard	5-100	20	100-2,000
7. Unattended Seismic Stations - Interagency	60	10-100	600-6,000
8. Missile Range Underwater Splash Detectors and Tracking Ship Position Fixers - Air Force	10	260	2,600

II Isotope Availability and Cost

Isotopes which are currently being produced as power sources for space radioisotope thermoelectric generators (RTG) are plutonium-238 for SNAP-9A and curium-242 for SNAP-11 and 13. Strontium-90 is used as a power source in the SNAP-7 series terrestrial generators.

The AEC has experience in producing Pu-238 and plans to make 30 to 35 kilograms available prior to 1968, which at a 5% overall RTG efficiency, would provide about 900 eW of power. Thereafter, estimated annual availability is equivalent to about 550 eW by the end of 1968, increasing to about 800 eW by the end of 1972. For planning purposes, these availability figures roughly represent a lower limit to the amount of Pu-238 that could be produced by the AEC at a cost of about $450 per gram ($16,000 per eW). The upper limit on availability at this cost is not likely to exceed twice the amounts stated above. Alternatives for substantially increasing Pu-238 availability are concomitant with unit costs of several thousand dollars per gram. Hence, expanding AEC production of Pu-238 with its concomitantly higher unit cost may be undesirable, unless the user agencies specifically request additional amounts of this isotope in spite of its cost.

Radioisotopes which have possible use as heat sources and which would be available during the next several years, in addition to Pu-238, are strontium-90, cesium-137, promethium-147, and curium-242*. The anticipated

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*See Appendix for Table of Characteristics of Radioisotopic Heat Sources.

annual availabilities and unit costs during the 1964-66 period are:

Isotope	Annual Capacity	Unit Cost
Strontium-90	3 to 5 Mc*	$1.00-1.50/c
Cesium-137	1 to 3.5 Mc	$0.80/c
Promethium-147	0.3 Mc	$0.75/c
Curium-242	150 grams	$12,700/g

*Million curies

Again, assuming a 5% overall RTG efficiency in converting isotopic heat output to usable electric power, the thermal output from the above isotopes at the time of separation and purification might provide the following amounts of electric power:

Strontium-90	1,000 to 1,600 eW/yr	$3,000-4,500/eW
Cesium-137	250 to 850 eW/yr	$3,500/eW
Promethium-147	6 eW/yr	$40,000/eW
Curium-242	900 eW/year	$2,000/eW

The short half-life of Cm-242 (163 days) radically affects the cost of power. For example, the cost of providing one electrical watt at the end of a one year mission would be $10,000, or roughly five times the cost of power from freshly separated Cm-242. Because of its rapid decay, Cm-242 is not considered a candidate for terrestrial applications. The Sr-90 half-life of 28 years, relatively low cost, and sufficiently high power density from various compounds makes it a feasible RTG fuel for either space or terrestrial applications. The very low power density of suitable Cs-137 compounds, plus the fact that a large fraction of the heat energy must be recovered from gamma radiation, limits its use to terrestrial applications. The cost of Pu-238, relative to Sr-90 or Cs-137, virtually precludes its use from other than very special terrestrial systems. Because of its low radiation background, Pm-147 like Pu-238 is an attractive candidate for space applications. Several other fuels such as cerium-144, polonium-210, thulium-170, cobalt-60, uranium-232, thorium-228, and mixed fission products have also been considered as possible heat sources. However, they are generally marginal compared with the other isotopes discussed above from the standpoints of production feasibility, properties, and cost.

Comparing isotope availability from present facilities with potential space requirements, it is apparent that the electrical power from Pu-238 that could be made available is far short of possible space power requirements. This situation is not significantly affected by either the Pm-147 or Cm-242 that might be available from present facilities. The 3 to 5 megacuries per year of Sr-90 from existing facilities would provide about 1,000-1,600 eW of power. However, its future large scale use in space is as yet undetermined. This is discussed later under safety considerations.

There are essentially two alternatives by which the AEC could substantially increase the availability of isotopes suitable for use as heat sources. One is large scale purification and encapsulation of radioactive fission products in the Hanford wastes and the other is to produce curium-244. However, neither of these would aid to the availability of isotopes prior to 1967 or 1968.

The Commission is proceeding with plans for a fission product recovery, purification, chemical conversion, and encapsulation facility at Hanford. The processing capacity for this facility is yet undecided, but it is not unreasonable to assume that it will be in the neighborhood of:

Isotope	Annual Capacity	Unit Cost
Strontium-90	10 Mc	10-15¢/c
Cesium-137	10 Mc	6¢/c
Cerium-144	100 Mc	1¢/c
Promethium-147*	15 Mc	7-10¢/c

*Aged one half-life.

The above unit costs are at best rough estimates and serve merely to indicate what might be expected from such a facility if operated at its rated capacity. Assuming a 5% overall RTG efficiency, the output of Sr-90 might provide in excess of 3,000 eW of power per year; Cs-137 about 2,500 eW; and at the time of separation, 270 eW from the Pm-147 and 40,000 eW from the Ce-144 (although its short half life of 284 days introduces power flattening problems in RTG applications.)

Curium-244 is of particular interest because of its extremely desirable characteristics for SNAP applications - notably an eighteen year half-life and a specific power more than three times greater than any other suitable long life isotopes. Because of its specific power, Cm-244 could be used in conjunction with thermionic converters, which are expected to be roughly twice as efficient in converting heat to electricity as thermoelectric converters, thereby optimizing the use of a valuable and limited resource. A study of large-scale Cm-244 production indicates that significant outputs of relatively pure Cm-244 could be produced at a cost in the range of $1,000 to $2,000 per gram. Several years of in-pile irradiation, out-of-pile cooling, and reprocessing are required in producing curium of high purity in the 244 isotope. The annual output during the first few years thereafter might be between 20 and 30 kilograms, and could provide roughly 6,000 to 8,000 eW in thermionic generators operating at 10% overall efficiency or 3,000 to 4,000 eW of power per year in RTG's operating at 5% overall efficiency.

A program to produce 3 kilograms of Cm-244 will begin in the Spring of 1964. This will provide production and separations experience as well as the necessary material to demonstrate the feasibility of using Cm-244 for space applications.

III <u>Isotopic SNAP Safety and Radiation Considerations</u>

Once an isotope generator has successfully been placed in a long life (more than 200 years) orbit, the isotope will decay to an insignificant activity level prior to returning to the earth. However, earlier random re-entry of highly active isotopes could take place in the event of failure to achieve the intended long life orbit after high velocities had been reached. The question that arises is should capsules be designed to burn-up or return intact? Burnup adds to radioactive fallout and considerations such as the amount of Sr-90, Pu-238, Cm-244, etc. that would be introduced as fallout and that could be safely tolerated, the fallout particle size, and the distribution of fallout must be evaluated in deciding whether a given strength fuel source should be designed for burnup. Some idea of the magnitude of this problem may be gleaned from the following: 10 megatons of fission yield produce approximately 1 megacurie of Sr-90. The approximate fission yields of nuclear weapons tests conducted in the atmosphere by all nations through 1962 produced about 19 Mc of Sr-90. A single 100 eW RTG fueled with Sr-90 would contain about 1/3 Mc, which if burned up due to a faulty or short lived orbit would be equivalent to that produced by 3 megatons of fission yield. With regard to Pu-238, one SNAP 9A, if burned up after early return would add a significant fraction to the 38,000 curies of Pu-238 and 164,000 curies of Pu-239 activity estimated to be in the stratosphere as of mid-1963. Moreover, the maximum permissive concentration of Pu-238 in air for the general population is about 150-200 times less than that of Sr-90, and Cm-244 is about 30-70 times less than Sr-90.

Capsules not burned up might return on land. Recent calculations indicate that the radiation dose at 1 foot from a relatively unaged encapsulated fuel source designed for a 10 eW and 100 eW RTG might be as follows:

	Rem per hour at 1 foot*	
	10 eW	100 eW
Pu-238	0.2	2.0
Pm-147	0.25	2.5
Cm-244	6	60
Sr-90	325	1650

The Sr-90 and Cm-244 dose rates are such that it appears necessary to either recover the capsules promptly or assure that they do not return on land if returned intact. This would require either very accurate tracking, an independent system for controlled re-entry, or injection into outer space.

Promethium-147 and perhaps plutonium-238 could return intact from short lived or faulty orbits and because of their very low radiation, might not necessarily need to be deliberately recovered.

The above dose rates also present a fuel handling problem at the launch site. A generator loaded with Cm-244 would require some shielding on the gantry if personnel were to work nearby; a Sr-90 fueled generator most certainly would. It might be preferable to load encapsulated Cm-244 into a generator either remotely or with tongs just prior to launch and thereby avoid the problems concomitant with shielding and personnel radiation monitoring. Encapsulated Sr-90 sources require remote loading just prior to launch. Remote handling on the missile gantry introduces

*Equivalent of 1 cm of lead assumed for attenuation of very soft gamma.

complications which are not shared by Pu-238 and Pm-147 due to their low radiation backgrounds.

Generators fueled with Cm-244 or Sr-90 require either shielding or separation from the spacecraft to avoid long term radiation damage to vulnerable payload components such as germanium and silicon semiconductors. Shielding the payload can impose a severe penalty on the total weight associated with the auxiliary power system, depending on the source strength, geometry, and distance from the dose point. This can be avoided by physically separating the isotopic generator from the electronics with a boom. The boom lengths required are roughly as follows:

Generator Power eW	Boom Length - Feet* Sr-90	Cm-244
25	7	5
100	12	11
250	16	17
1000	30	34

*Separation of isotopic source and payload needed to confine integrated dose to 10^6 rad and 10^{12} n/cm^2 in 5 years with no shielding.

Booms might be in a folded attitude during launch and deployed after injection of the spacecraft into orbit. The Navy navigational satellites use a 60 foot boom; the NASA Orbiting Geophysical Observatories will have various experiments requiring preferred orientations or isolation mounted on external booms, etc. so that booms are not uncommon to today's spacecraft.

IV <u>The Economics of Isotopic SNAP</u>

Economics apparently are presently a major consideration in the various non-defense SNAP terrestrial applications, especially in cases such as replacing batteries with isotopes in buoys and remote shore lights. Such specialized terrestrial applications do not lend themselves readily to a generalized analysis. Therefore, the purpose of this section is mainly to view the economics of SNAP for space power.

While the costs associated with a single SNAP unit are relatively minor compared with the total cost of a space mission, there are several satellite systems presently planned which may require several thousand electrical watts from many units. In such applications the cost of the power source becomes very significant.

Studies indicate that the energy from a 25-50 eW radioisotopic thermoelectric generator (RTG) fueled with Pu-238, e.g. SNAP-9A, or fueled with Cm-242, e.g. SNAP-11, costs as much or more than energy from unoriented solar cell systems of similar capacity. Figures 2 and 3 show that Cm-242 is apparently only competitive in short missions (1 year or less) and Pu-238 for long missions (5 years). A 25-50 eW RTG fueled with Sr-90 at the 1964 anticipated cost of $1.50 per curie, and separated from the payload by a boom rather than shielded, appears

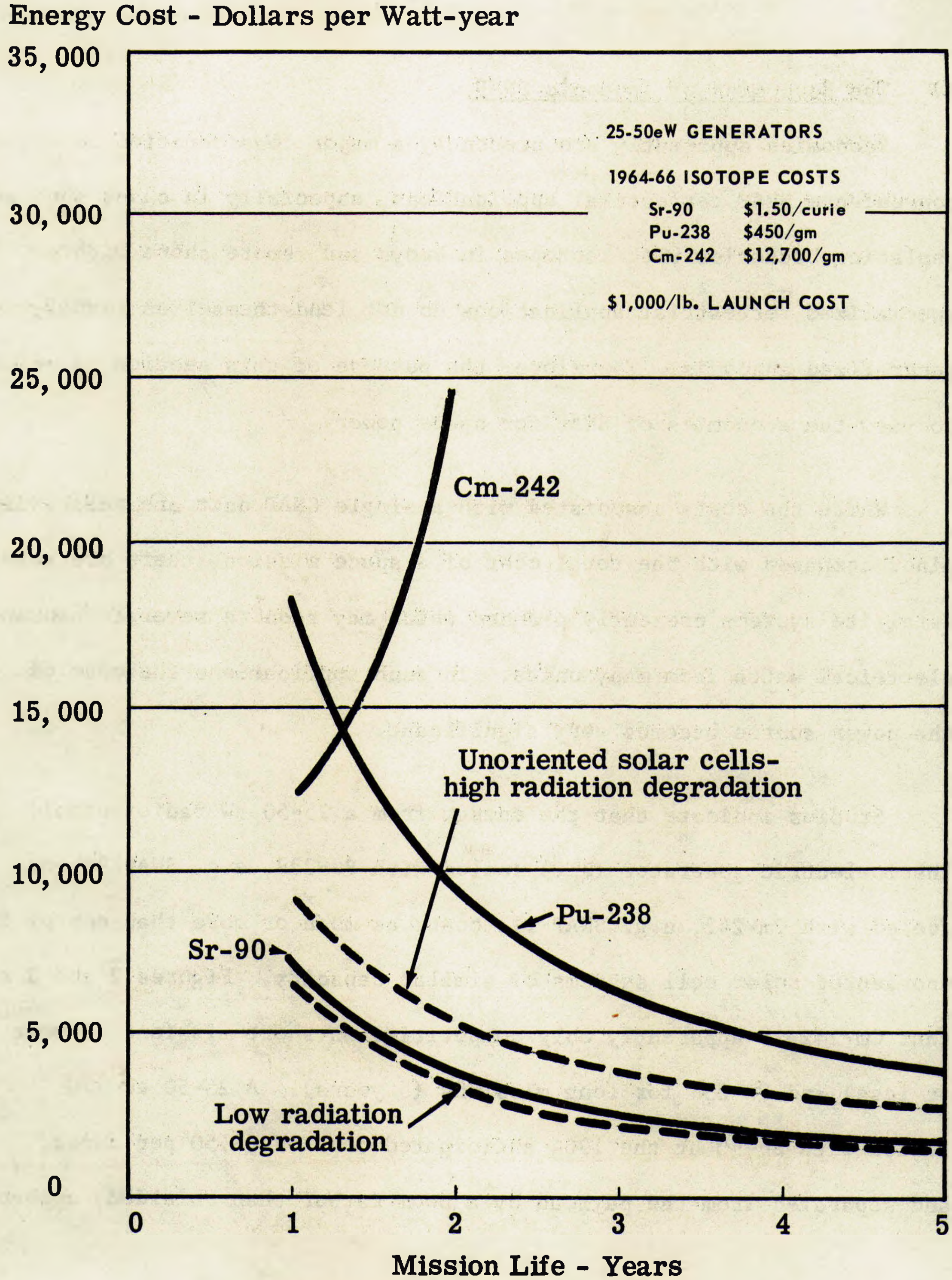

Figure 2

COST OF ENERGY vs MISSION LIFE
1964-66 ISOTOPE COSTS & $1,000/lb. LAUNCH COST

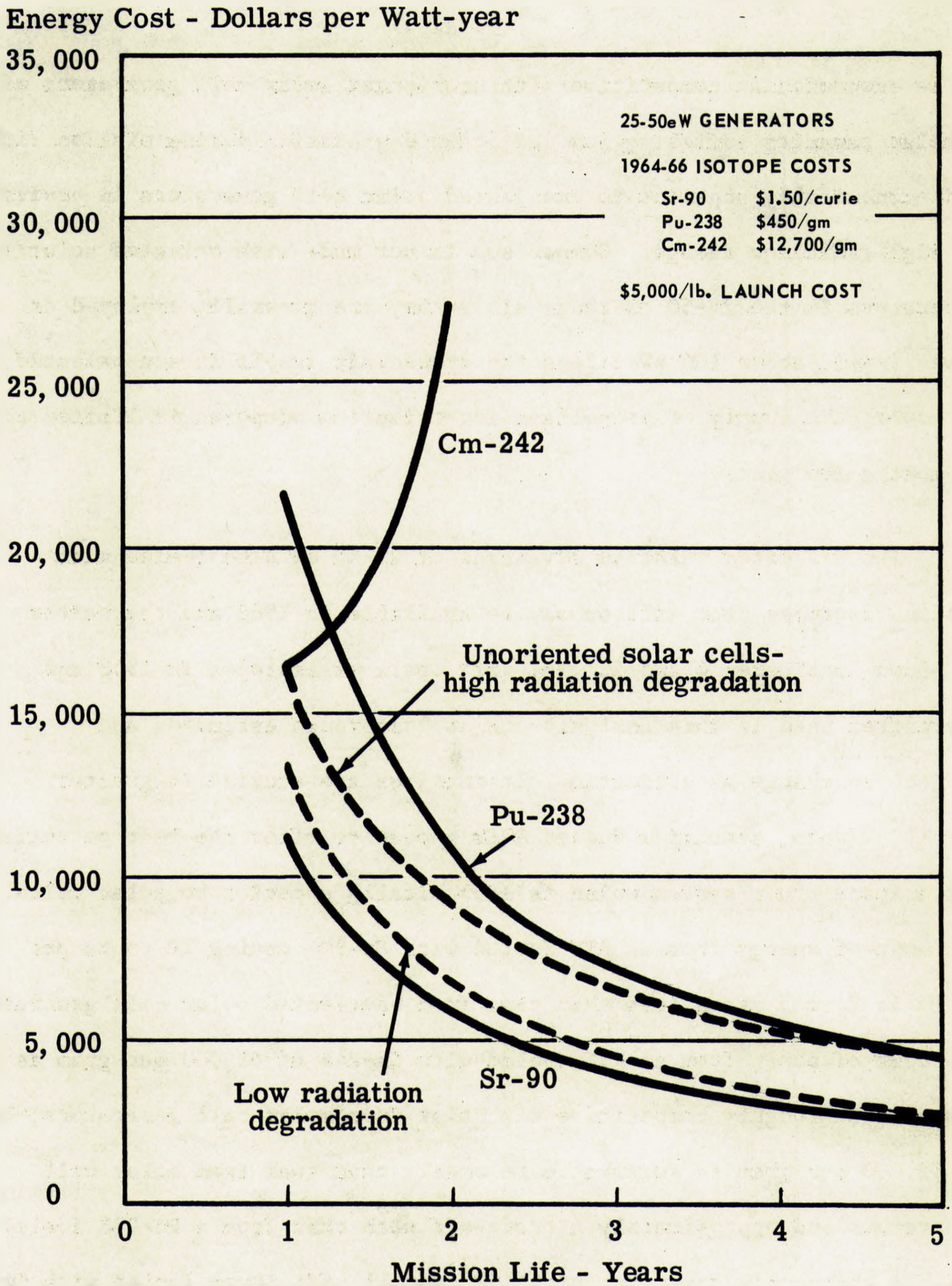

Figure 3

COST OF ENERGY vs MISSION LIFE
1964-66 ISOTOPE COSTS & $5, 000/lb. LAUNCH COST

to be economically competitive with unoriented solar cell generators of similar capacity suffering low radiation degradation during mission life, and economically superior to unoriented solar cell generators in orbits of high radiation damage. Comparison is not made with oriented solar cell generators in the 25-50 eW range since they are generally employed at power levels above 100 eW unless the spacecraft itself is sun-oriented. Moreover, the supply of propellant for orienting purposes is limited to at most a few years.

The estimated relative advantage of 25-50 eW RTGs fueled with various isotopes that will or may be available in 1968 and thereafter is shown in Figures 4 and 5. The unit costs of isotopes in 1968 and thereafter used in this analysis are at best rough estimates and subject to change as production alternatives are studied in greater detail. Again, strontium fueled RTGs appear to offer the best potential for a space power system which is economically superior to solar cells. The cost of energy from an RTG fueled with Sr-90 costing 10 cents per curie is 2 to 5 times less than that from unoriented solar cell generators. The cost of power from an RTG fueled with Cm-244 at $1,000 per gram is shown to be roughly competitive with that from solar cell generators, but at $2,000 per gram is somewhat more costly than that from solar cell generators and approximately a trade-off with that from a Pu-238 fueled RTG. A thermionic generator with 10% overall efficiency fueled with Cm-244

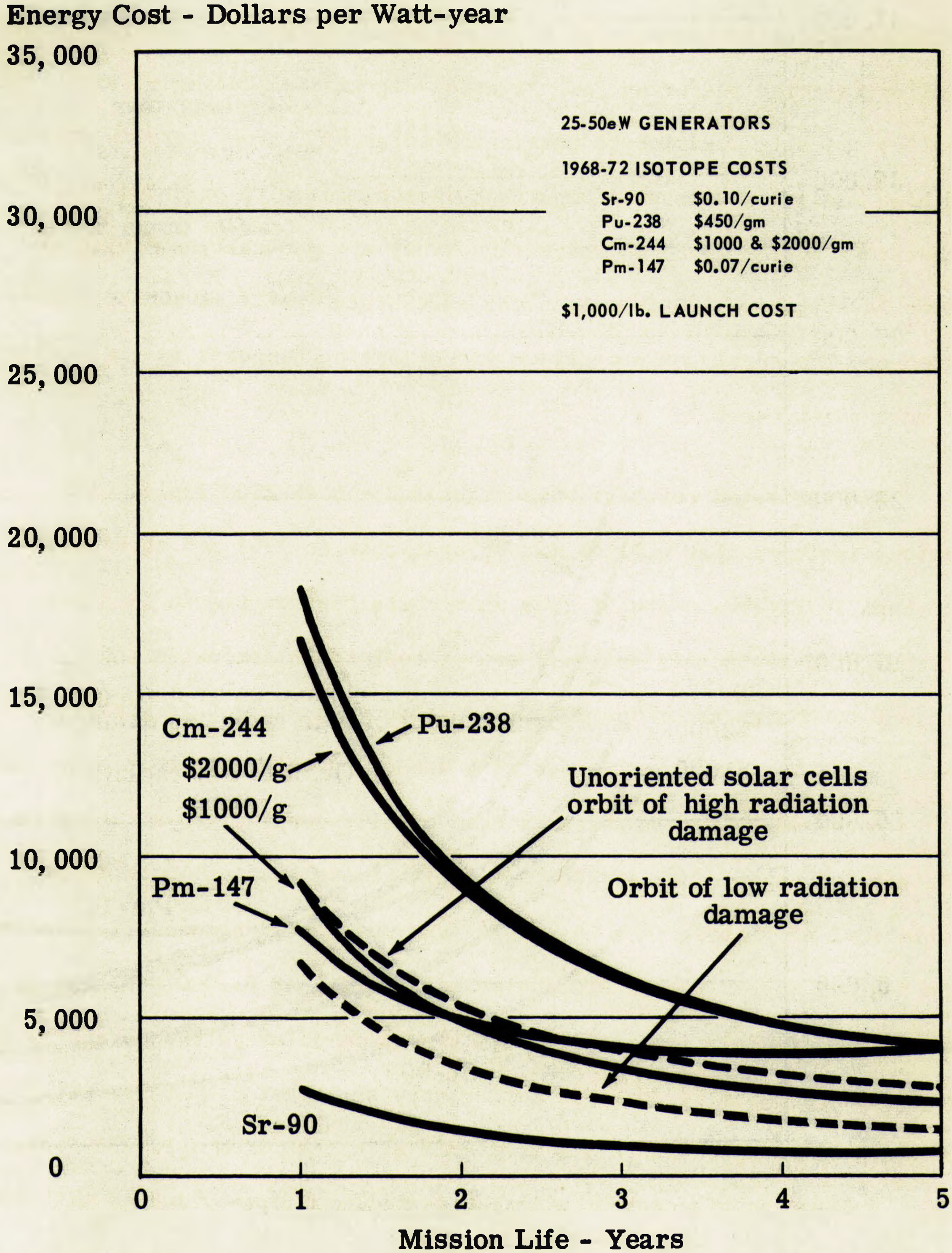

Figure 4

COST OF ENERGY vs MISSION LIFE
ASSUMED 1968-72 ISOTOPE COSTS & $1,000/lb. LAUNCH COST

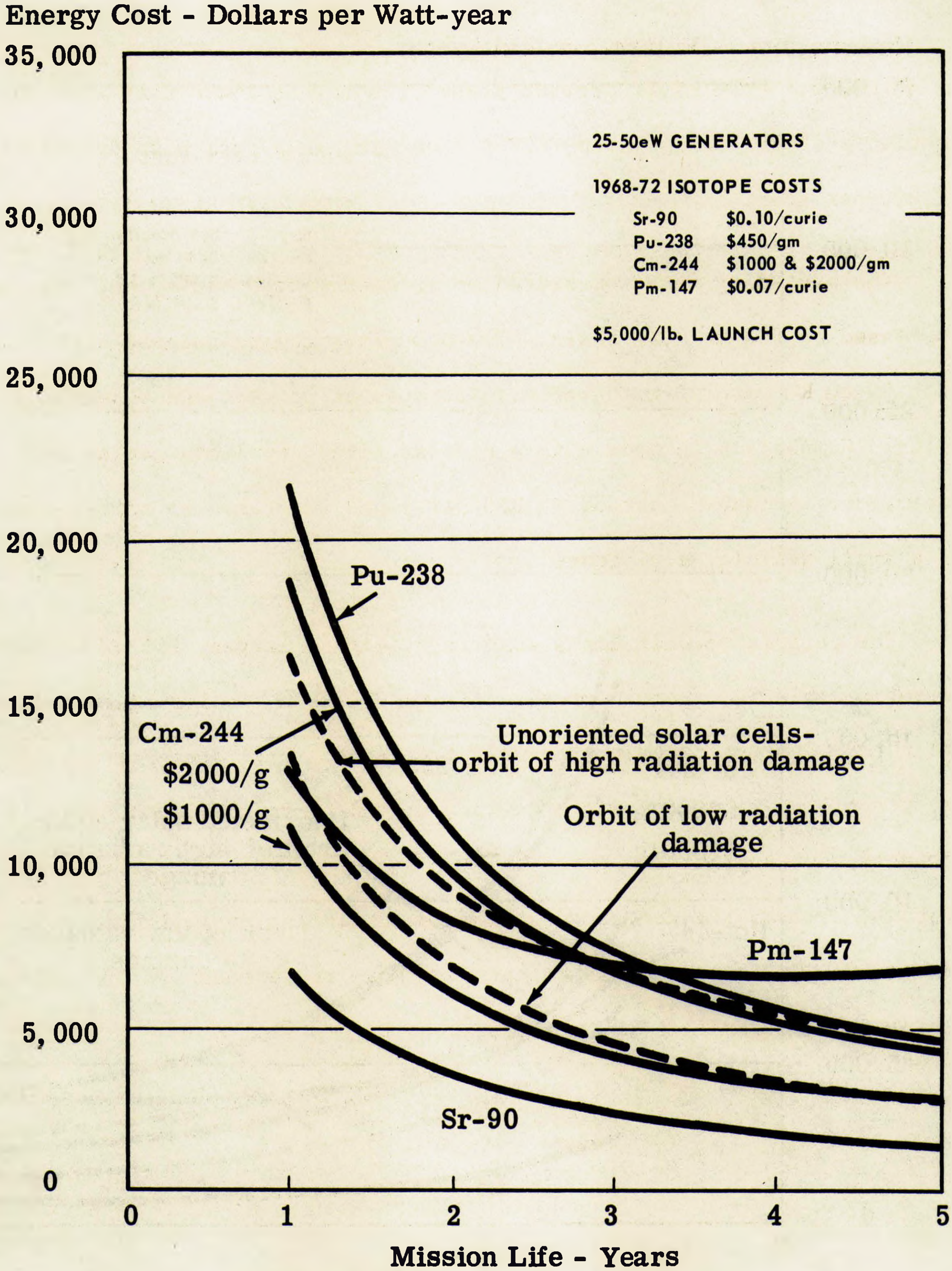

Figure 5

COST OF ENERGY vs MISSION LIFE
ASSUMED 1968-72 ISOTOPE COSTS & $5,000/lb. LAUNCH COST

at $1,000 per gram might provide power at somewhat lower cost than an unoriented solar cell system, or at about the same cost with Cm-244 at $2,000 per gram.

The preceding data, presented on an energy cost basis, may also be expressed on a unit cost basis. Table 9 gives the calculated unit costs of a 25 eW RTG fueled with various isotopes at present and possible future costs. Comparison is made with a similar sized unoriented solar cell generator. A launch cost of $5,000 per pound was taken as representative of a small vehicle, e.g. Scout.

The calculated unit costs associated with a larger, 150 eW RTG are given in Table 10. Here comparison is made with a similar sized oriented solar cell system; however, the weight of that system does not include the propellant necessary for orientation, and hence the launch cost is probably underestimated. Moreover, the assumed three year life probably exceeds the normal provision for orienting propellant. A launch cost of $3,000 per pound was selected as more representative of a larger vehicle, e.g. Thor-Agena B or Atlas-Agena B.

TABLE 9

COST COMPARISON

25 eW RADIOISOTOPE THERMOELECTRIC GENERATOR & UNORIENTED SOLAR CELL GENERATORS

		Thousands of Dollars			
Isotope	Unit Cost	Cost of Isotope	Generator Cost	Launch Cost	TOTAL
Cm-244	$1,000/gm	$200	$ 35	$ 65	$300
	2,000/gm	400	35	65	500
Pu-238	$450/gm	410	35	100	545
Sr-90	$1.50/curie	130	35	125	290
	0.10/curie	10	35	125	170
Pm-147	$0.07/curie	210	35	275	520
Unoriented solar cells					
Orbit of low radiation damage -			125	210	335
Orbit of high radiation damage -			230	250	480

ASSUMPTIONS

1. Sufficient isotope and solar cells to provide 25 eW at end of 3 year mission, allowing for radioactive decay and solar cell degradation.

2.

Cm-244	2.8	thermal watts/gram pure isotope
Pu-238	0.56	" " " " "
Sr-90	0.90	" " " " "
Pm-147	0.33	" " " " "

3. 5% overall efficiency for isotopic thermoelectric generators.

4. Generator costs: Unoriented solar cells - $5,000/eW in orbits of low radiation damage; $9,500/eW in orbits of high radiation damage for 3 years; $1,500/eW for isotopic thermoelectric generators.

5. Generator weights:

Cm-244	0.5 lb/eW
Pu-238	0.8 lb/eW
Sr-90	1.0 lb/eW
Pm-147	2.2 lb/eW (3 yr. mission)
S/cells	1.7 lb.eW - assuming low radiation damage
	2.0 lb/eW - allowing for high radiation damage

6. $5000/lb launch cost.

TABLE 10

COST COMPARISON

150 eW RADIOISOTOPE THERMOELECTRIC GENERATOR & ORIENTED SOLAR CELL GENERATORS

Isotope	Unit Cost	Cost of Isotope	Generator Cost	Launch Cost	TOTAL
		Thousands of Dollars			
Cm-244	$1,000/gm	$1,200	$150	$110	$1,460
	2,000/gm	2,400	150	110	2,660
Pu-238	$ 450/gm	2,470	150	225	2,845
Sr-90	$1.50/curie	765	150	300	1,215
	0.10/curie	50	150	300	500
Pm-147	$0.07/curie	1,255	150	585	1,990
Oriented solar cells					
Orbit of low radiation damage		-	150	290	440
Orbit of high radiation damage		-	375	330	705

ASSUMPTIONS

1. Sufficient isotope, solar cells, and propellant for solar cell orientation, to provide 150 eW at end of 3 year mission, allowing for radioactive decay and solar cell degradation.

2. Cm-244 2.8 thermal watts/gram pure isotope
   Pu-238 0.56 " " " " "
   Sr-90 0.90 " " " " "
   Pm-147 0.33 " " " " "

3. 5% overall efficiency for isotopic thermoelectric generators.

4. Generator costs: Oriented solar cells - $1,000/eW in orbits of low radiation damage; $2,500/eW in orbits of high radiation damage for 3 years; $1,000/eW for isotopic thermoelectric generators.

5. Generator weights:

Cm-244	0.25 lb/eW
Pu-238	0.5 lb/eW
Sr-90	0.67 lb/eW
Pm-147	1.3 lb/eW (3 yr. mission)
S/cells	0.65 lb/eW - assuming low radiation damage
	0.73 lb/eW - allowing for high radiation damage

6. $3000/lb launch cost.

V Discussion

The justification of isotopic SNAP, as contrasted with alternative sources of power, is that such systems are superior in satisfying some or most of the following criteria:

1. maximum reliability
2. minimum system cost
3. minimum space, weight, and payload interface requirements
4. maximum useful life - radiation resistance
5. maximum structural integrity
6. compatibility with environment
7. maximum safety - minimum radiation hazard

These criteria are, of course, of varying importance depending upon the specific application.

The two 2.7 eW modified SNAP-3 and the two 25 eW SNAP-9A generators oriented to date have demonstrated the feasibility of isotopes in space, as well as providing valuable experience in the integration of these units into satellites and in establishing pre-launch interagency procedures and policies. A similar conclusion can be reached regarding the terrestrial applications to date. However, additional experience and quantitative evidence are required to judge more fully the merits of isotopic SNAP against the above criteria.

Major uncertainties related to the safety of large scale use of isotopes in space, isotope availability, cost, sustained generator performance, and ground handling of sources with high radiation backgrounds need to be resolved. A large scale program for isotope heat source application clearly depends on the resolution of these problems. The reluctance of NASA, DOD, and other agencies to establish firm requirements for isotopic space and terrestrial power systems is symptomatic of the above uncertainties.

The radiation hazard appears to be the key problem associated with future large-scale application of radioisotopes as heat sources in thermoelectric or thermionic generators. Isotopes can represent serious radiation hazards under certain types of system malfunctions. In space applications of isotopic SNAP, failure to achieve an intended orbit may result in return of relatively undecayed isotopes either intact or as fallout, depending mainly upon the fuel capsule design. A thorough evaluation of the risks implicit in large scale utilization of isotopes in space, and guidance regarding the allowable magnitude of future applications is a prerequisite to endorsing any large scale program for using isotopes in space.

Terrestrial isotopic SNAP applications are of a more controllable nature, and it should be possible to design containment devices and to develop relatively insoluble chemical fuel forms which can meet safety standards. However, there is a need to provide guidance in system design first by developing safety standards.

Finally, the cost of the isotopic fuel can dominate the total cost of a SNAP device, as shown in Tables 9 and 10. Hence, it should be a parameter users factor into their choice of a specific isotope as well as their selection of a nuclear or non-nuclear system.

APPENDIX

SYSTEMS FOR NUCLEAR AUXILIARY POWER

ISOTOPE POWER GENERATORS

UNIT'S DESIGNATION	USE	POWER (eW)	WEIGHT (lbs)	ISOTOPE	UNIT'S DESIGN LIFE	STATUS
	SPACE APPLICATIONS					
SNAP-1	Air Force Satellite	500	-	Ce-144	6 mo.	Program cancelled
SNAP-1A	Air Force Satellite	125	175	Ce-144	1 yr.	Program cancelled
SNAP-3	Demonstration device	2.5	4	Po-210	90 days	Program completed
Undesignated (Modified SNAP-3)	Navy navigational satellites	2.7	4.6	Pu-238	5 yrs.	2 in space, 6/61 & 11/61, first in operation, second failed after 8 mo.
SNAP-9A	DoD [redacted] satellites	25	27	Pu-238	5 yr. mission	2 in space, 9/63 & 12/63, both in operation
SNAP-11	Moon probe (Surveyor)	21-25	30	Cm-242	90 day mission	Being tested*
SNAP-13	Thermionic development demonstration device	12	4	Cm-242	90 day mission	Fabrication of fueled unit
SNAP-17	Communication satellite	25	28	Sr-90	5 yrs.	Just initiated
SNAP-19	IMP, Nimbus	20	18	Pu-238	5 yrs.	Design study stage
Undesignated	Lightweight demonstration device	6-10	3	Pu-238/Sr-90	>1 yr.	Being tested*
	TERRESTRIAL APPLICATIONS					
Undesignated	Axel Heiberg weather station	5	1,680	Sr-90	2 yrs. minimum	Operating since 8/61
SNAP-7A	Navigational buoy	10	1,870	Sr-90	10 yrs.	Operating since 1/64
SNAP-7B	Fixed navigational light	60	4,600	Sr-90	10 yrs.	Operating since 11/63
SNAP-7C	Weather station	10	1,870	Sr-90	10 yrs.	Operating since 2/62
SNAP-7D	Floating weather station	60	4,600	Sr-90	10 yrs.	Operating since 1/64
SNAP-7E	Ocean-bottom beacon	6.5	6,000	Sr-90	10 yrs.	Undergoing repairs
SNAP-15A/B	Nuclear Weapons	0.001	1	Pu-238	4 yrs.	Being tested*
SNAP-21	Ocean bottom	10		Sr-90	5 yrs.	Just initiated
Undesignated	Undersea Seismograph	5	500	Cs-137	>1 yr.	Terminated
Undesignated	Demonstration device	5	-	Mixed Fission Products	>1 yr.	Being tested*

*Electrically heated generator.

SYSTEMS FOR NUCLEAR AUXILIARY POWER

SPACE REACTOR POWER GENERATORS

UNIT'S DESIGNATION	USE	POWER, KWe DESIGN	POWER, KWe POTENTIAL	WEIGHT (lbs)	UNIT'S DESIGN LIFE	PROJECT STATUS
SNAP-10A	Thermoelectric demonstration system	0.5	2	1,000	1 yr.	Nearing completion
SNAP-2	Rankine cycle demonstration system	3	10	1,470	1 yr.	[redacted] Reoriented
SNAP-8	Communication satellites or space station	35	--	6,000(est.)	10,000 hours	Reactor power test in progress
SNAP-50	Electric propulsion and auxiliary power	300	1,200	6,000(est.)	10,000 hours	Component development

CHARACTERISTICS OF ISOTOPIC HEAT SOURCES

	Strontium 90	Cesium 137	Promethium 147	Plutonium 238	Curium 244	Curium 242	Polonium 210	Cerium 144	Cobalt 60
Type of decay	Beta	Beta-Gamma	Beta	Alpha	Alpha	Alpha	Alpha	Beta-Gamma	Beta-Gamma
Half Life, years	28	30	2.7	89	18	0.45	0.38	0.78	5.3
Specific Power of Isotope, th. watts/gram	0.90	0.42	0.33	0.56	2.8	120	141	25.6	17.4
Estimated Isotopic Purity, %	50	35	95	80	98	90	95	18	10
Typical Fuel Form	SrO	Glass	Pm_2O_3	PuO_2	Cm_2O_3	Cm_2O_3	Metal	CeO_2	Metal
Active Isotope in Compound, %	42	16	82	71	89	82	95	15	10
Specific Power of Compound, th. watts/gram	0.38	0.067	0.27	0.39	2.49	98	134	3.8	1.7
Density of Compound, gm/cc	3.7	3.2	6.6	8.9	10.6	11.75	9.3	6.4	8.9
Power Density of Compound, th. watts/cc	1.40	0.21	1.8	3.5	26.4	1150	1210	24.5	15.5
Shielding Requirement	Heavy	Heavy	Minor	Minor	Moderate	Minor	Minor	Heavy	Heavy
Emission Requiring Shielding	Bremst'ng	Gamma	--	--	Neutron	--	--	Gamma	Gamma

Reference: Rohrmann, C. A., "Radioisotopic Heat Sources", HW-76323 Rev 1. October 15, 1963

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Space
12

First Launch of a Satellite Interception Attempt Using a THOR Missile Was Successfully Accomplished 15 February 1964

This first launch successfully accomplished all test objectives and demonstrated system capability to meet the stringent requirements for satellite interception. Telemetry and ground guidance data indicated a nominal trajectory was followed from lift-off through target interception. Lift-off occurred within less than a second of the previously computed lift-off time. The alternate missile was counted down, and was available for launch in case of malfunction of the primary missile. The long haul communications system performance was normal throughout the test period, with no outages recorded. System accuracy, as based on SPADATS prediction and on Sandia tracking equipment, is within specifications for a successful satellite interception.

Target was a TRANSIT 2A rocket body, inclination 66.7 degrees, apogee 564 n.mi., perigee 336 n.mi., period 101 minutes. The selected intercept point was at 443 n.mi. range from Johnston Island along an azimuth of 290 degrees, altitude 540 n.mi.

Special Access Required
Program 437

Downgraded at 3 year intervals;
declassified after 12 years.
DoD Dir 5200.10.

DoD 18 Feb 1964

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CONTROL: 11367
RECD: FEBRUARY 17, 1964, 2:17 P.M.

FROM: MOSCOW

ACTION: SECSTATE 2554

DATE: FEBRUARY 17, 8 P.M.

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PASS NASA

DURING CALL BY AMBASSADOR TODAY BLAGONRAVOV EXPRESSED OPINION ECHO II COOPERATION PROCEEDING SATISFACTORILY. HE REQUESTED NASA SEND TO SOVIET ACADEMY AND TO ZEMENKI EPHEMERIDES FOR 24-HOUR PERIOD PRECEDING JODRELL BANK-ZEMENKI TRANSMISSION SECHEDULED 1347 GMT FEB 21. HE NOTED PRESENT PLANS CALL ONLY FOR RECEPTION BY SOVIETS BUT DID NOT RULE OUT SOVIET TRANSMISSIONS AT LATER DATE.

GLAGONRAVOV PROPOSED DISCUSSION OF ESTABLISHMENT WORKING GROUP FOR COORDINATING METEOROLOGICAL SATELLITE LAUNCHES BE HELD AT TIME OF UN RPT UN OUTER SPACE TECHNICAL SUBCOMMITTEE MEETING MAY 22 TO JUNE 12 WHICH HE PLANS ATTEND. HE SUGGESTED DIRECT CORRESPONDENCE BETWEEN NASA AND SOVIET ACACEMY THIS REGARD. GLAGONRAVOV DID NOT RESOOND QUERY ABOUT US RPT US PROPOSAL TO APPROACH BRITISH POST OFFICE CONCERNING FINANCIAL ARRANGEMENTS FOR DIRECT DATA LINK. IN DISCUSSION US RPT US PROPOSAL OF LAST FALL FOR BILATERAL TALKS ABOUT WORLD WIDE SATELLITE COMMUNICATION SYSTEM, BLAGONRAVOV SAID AUGUST 16 MEMORANDUM PROVIDES INITIAL BASIS FOR COOPERATION WHICH COULD BE EXTESDED AND NOTED POSSIBILITY EXPLORING THIS SUBJECT AT TIME UN SUBCOMMITTEE MEETING. HE STATED SOVIETS HAVE NOT YET LAUNCHED COMMUNICATIONS SATELLITE WHICH STILL IN DEVELOPMENT STAGE.

CFN NASA BLAGONRAVOV ECHO II ZEMENK 24-HOOR JODRELL BANK-ZEMENKI 1347 GMT 21 22 12 NASA 16 UN

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Space

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UNITED STATES INFORMATION AGENCY
OFFICE OF THE DIRECTOR
WASHINGTON 25, D. C.

February 8, 1964

MEMORANDUM FOR: The Honorable
McGeorge Bundy
The White House

Attached is an interesting and heartening report on foreign reaction to our recent space achievements.

Don

Donald M. Wilson
Acting Director

Attachment

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UNITED STATES INFORMATION AGENCY

Research and Reference Service

FOREIGN REACTION TO
RECENT U.S. AND SOVIET SPACE ACTIVITIES

R-14-64

February 6, 1964

This is a research report, not a statement of Agency policy

TABLE OF CONTENTS

SUMMARY

The recent U.S. space successes received unanimous praise in the free world press, which gave the events moderate to heavy coverage. Leading papers throughout the world awarded the United States the "gold medal" in space weight-lifting for the first time since Sputnik. A few qualified their conclusion by admitting the lead may still be only temporary.

The more sophisticated papers in Europe and the Far East single out the technical feats that made the tests so successful -- precise mathematical calculations, superior guidance systems to permit rectifying Ranger's flight path, and the use of liquid hydrogen fuel. Most comment minimizes the failure of Ranger's cameras, explaining that corrections in later flights will certainly rectify the error.

Typically, papers term Saturn I a "sensational success", "a technological and scientific miracle", and "a decisive step toward the conquest of the moon." Papers in Europe and the Far East share the term "bulls-eye" to describe Ranger's success in hitting the small target on the moon. Papers throughout the world offer varying descriptions of the new American space lead, usually falling between the Japan Times "temporary lead" to Australia's conclusion of a "decisive lead."

The Saturn and Ranger shots drew widespread attention in both news and editorial sections of the press in Europe and the Far East, with Latin America reporting moderately. There was only light coverage reported from Africa and the Middle East. The inflated Echo and the two Soviet Elektrons drew little attention anywhere.

Comment acclaiming the U.S. space feats and resulting space lead dominated reaction in the free world. But the very success of the U.S. efforts produced the greatest attention ever to the prospects for U.S.-Soviet cooperation in space. Comment in Europe picked up the implication of Echo II for the hoped-for cooperation in space. A Dutch newspaper, for instance, termed it the first practical cooperative effort between the Americans and the Russians in space. A Brussels paper too termed this aspect the most "spectacular aspect" of Echo II.

Comment elsewhere in Europe, the Far East, the Middle East and Latin America quickly focused on the desirability of cooperation. Obvious free world relief that the United States had finally made the grade in space only served to remove obstacles to what many hoped would be favorable consideration of space cooperation.

A Canadian paper, for instance, observed that cooperation might be more likely now that U.S. honor had been satisfied with the launching of the largest pay load ever.

United States' allies in the Far East -- the Philippines and South Korea -- chose the occasion to advise cooperation. Manila papers assumed "the whole world" would benefit and a South Korean paper hoped for an end to the cold war as a result of space cooperation. Japan more soberly recommended exchange of data and other practical scientific cooperation, but saw military aspects of space exploration as a major obstacle. Papers in Latin America and the Middle East approved space cooperation.

There were some lamentations over the excessive cost involved in the competitive efforts of the U.S. and the USSR. Such comments either emphasized that cooperation would cut back the financial waste or that the resources could be put to better use in improving living conditions in less developed areas of the world.

The impact on the Soviet Union of the U.S. space successes was also the subject of varied speculation, with a British paper seeing U.S. success as an obstacle to Russian willingness to cooperate, and a French paper concluding, on the other hand, that Moscow might now see "new reasons for taking into consideration the suggestion of Presidents Kennedy and Johnson" for a joint assault on the moon.

The possibility of future space cooperation between Russia and the United States received implicit endorsement from Moscow in the marked approval it gave the Echo II experiment. In contrast, neither the Saturn nor Rangers shots drew more than perfunctory reports. On Echo, though, Moscow expressed the hope that it "would be long-lived, meet all the test objectives, and that thus the first Soviet-American space experiment would be a success." A Soviet scientist saw a strengthening of "friendly scientific ties".

Communist comment on Saturn I ranged from the Italian Communist *Unita's* grudging comment that it marked a "turning point in U.S. astronautics" to Cuba's plaint that Saturn carried "the most useless satellite" into space so far. East European comment noted defensively that Soviet rocketry was "still a match" for the United States, while Moscow only reported factually that the satellite weighed 17 tons. Peking reported, factually and without comment, the launchings of Saturn I and the Soviet Elektrons.

WESTERN EUROPE

The "great NASA week begun on 21 January" delighted West Europeans who saw the success of Saturn I and Ranger VI definitely putting the U.S. ahead in the "space race" and on its way to the moon. Saturn I was hailed for the magnificence of its thrust and heavy payload and the use for the first time of liquid hydrogen for fuel. Ranger VI was given accolades for the precision of its flight and landing, despite the disappointing last minute failure of its cameras. The successful launching of the Soviet Elektron 1 and 2, however, served to reinforce the view of many that the U.S. and USSR should cooperate rather than compete in space endeavors.

Banner headlines and extensive front-page articles gave detailed scientific coverage of the two American exploits.

Echo II and the Soviet Elektrons were given only moderate coverage and received little editorial comment.

U.S.-USSR: A Comparison

Media across the continent, with few exceptions, agreed that the U.S. had made a spectacular advance with the launching of Saturn I. It had surged ahead of the USSR in "this costly race which is still very much 'on'" (London's conservative Daily Telegraph) and had perfected the first step of the moon journey. Corriere della Sera, Italy's most influential paper, carried a 7-column headline proclaiming: "America gains a very great advantage over Russia." Other papers called Saturn a "sensational success", "a technological and scientific miracle," "a decisive step toward the conquest of the moon." Rightist Giornale d' Italia saw it as a great victory of President Kennedy's faith in scientific progress. "Americans are slow to start," Le Figaro said, "but when they acknowledge the necessity of an effort, they start powerfully."

The rightist L'Aurore in Paris editorialized:

> With their giant rocket the Americans have just outrun the Russians. In less than ten minutes, the NASA experts achieved a triple threat. They ran the most powerful rocket in the world ever fired: 17 tons of thrust. They placed in orbit the heaviest satellite ever

> launched. They succeeded in using smoothly the most dynamic fuel ever used in a missile: liquid hydrogen. In so doing, they won the first lap in the race to the moon... The U.S. henceforth knows that the feat of the century is within its reach.

Unita, party organ of the Italian communist party, conceded that Saturn I marked a "turning-point in U.S. astronautics."

Amid the general acclaim, a few notes of caution were voiced. Without down-grading the U.S. achievements, Parisian Le Monde declared U.S. superiority relative because the currently operational Soviet rockets were "perfectly developed while the American device is still in an experimental phase." Independent-left Combat, Paris, pointed out that the record of "duration in orbit" belonged to the Soviets who seemed much nearer than the U.S. in "achieving a rendezvous in space."

With praise for the Saturn rocket still reverberating, Ranger VI further delighted West Europeans as a "U.S. technical achievement of the highest order," despite its disappointing failure to return photographs of the moon.

"We are happy," said Gaullist La Nation, "to pay tribute to American science and to welcome this success with the entire American people." The precision with which Ranger VI hit the selected moon spot -- the "bulls eye" -- and the ease with which its flight was corrected by a radio signal from the earth impressed the Daily Telegraph as a "triumph of navigation", a viewpoint shared generally by the West European press. The pro-Labor Daily Mirror found it a "dramatic and awe-inspiring achievement of earth-bound man."

Speculation on the last minute camera failure of Ranger VI, led most commentators to guess that it lay in the electronic equipment controlling the camera. There was confidence, however, that this was only a temporary set-back for the U.S. which would be corrected in future moon shots. The Laborite Daily Herald declared that despite its failure to take pictures, it was a "wonderful shot." The camera failure, according to center-right Il Resto del Carlino, Bologna, did not cloud the great success achieved in the "brilliant launching and the perfection of the calculations which took Ranger VI along a perfect route." Le Monde stated that, from a ballistic viewpoint, the Ranger test was "fully successful. This should be an encouragement to the Americans, despite camera disappointment, and a spur to NASA leaders to redouble their efforts."

Echo II received only moderate attention in the West European press. Brief factual accounts, as often as not on inside pages, told the story. Editorial comment was sparse. Some editors felt as did the Progressive Catholic Volkskrant, Amsterdam, that "technically there is little news in the ...test."

In Canada Echo II was praised because of its "clear visibility" from earth. The science editor of the Toronto Globe and Mail, declared that people around the world had gotten a new impression of the U.S. and "seemed automatically to assume that the nation which could add a new star to the heavens must also stand high in other accomplishments."

U.S.-USSR: Hopes for Cooperation

The separate successes of the U.S. and the USSR within the past week led many commentators to suggest and to hope for a future U.S.-USSR cooperative effort in space. For each nation separately to "grasp for the moon" led the conservative Daily Mail, London, to lament this "senseless duplication of effort and waste of resources." The conservative Daily Telegraph, London, pointed out that the current space efforts were complementary, even though not yet cooperative for the object of the American probe was to investigate the problem of landing on the moon while that of the Soviet stations -- Electron I and II -- was to study the radiation belts which may make it hazardous for a man to get there.

The matter of costs in the separate U.S.-USSR experiments concerned a number of commentators, particularly in Canada and in Britain. The Labour Daily Herald, London, as well as the independent Toronto Telegram felt that the money saved in cooperative efforts could well be used to raise living standards on the earth. Russian national pride was seen by the Daily Mail as the obstacle preventing the USSR from accepting the U.S. as a partner as the U.S. had suggested. Toronto's Daily Star hoped that, now that the U.S. had launched a larger pay-load than the Russians, perhaps the U.S. national honor had been satisfied and an appropriate time had arrived for the two nations to work together. Le Monde, sounding a somewhat more hopeful note, thought that perhaps Moscow might now see in the success of Saturn I "new reasons for taking into consideration the suggestion of Presidents Kennedy and Johnson of organizing a joint assault on the moon."

In commenting on Echo II, Volkskrant, Amsterdam, along with papers in other countries, placed emphasis on the fact that the first practical cooperative effort between the American and the Soviets in the area of space travel had been projected. The Flemish nationalist De Standaard, Brussels, termed it the "spectacular aspect" of the affair.

FAR EAST

Press reaction to the launching of Saturn I and Ranger VI was fairly widespread in the Far East, heavy in Japan. Little mention has been made of the Soviet Elektrons. All reports credit the United States with having caught up with the Soviet Union in space exploration. Most comments placed the United States in the lead. Most comment expressed hope for cooperation, rather than competition, in space exploration -- especially cooperation between the United States and the Soviet Union. Peking reported, factually and without comment, the launchings of Saturn I and the Soviet Elektrons.

U.S.-USSR: A Comparison

Japanese newspapers were enthusiastic over the recent spectacular achievements of the United States. Yomiuri, one of Japan's three leading national dailies, hailed Ranger VI's "spectacular bull's eye hit on the moon." Yomiuri said: "After traveling about 65 1/2 hours in deep space, the United States lunar probe rocket Ranger VI hit its moon target, the Sea of Tranquility. The designated target area and the time it cracked onto the moon surface were precise and as per schedule. This success confirms the steady progress the United States has been achieving in the field of rocket guidance technique." Commenting on the failure of the cameras to function, Yomiuri said: "It is indeed regrettable. We can understand the NASA people's disappointment over the failure." The tone was definitely one of complete sympathy, not criticism; and the paper went on to express confidence that the United States would analyze the cause of the failure and would correct the defect in future moon probes.

Turning to the success achieved by Saturn I, Yomiuri commented: "What is more significant to the progress made by the United States in space development is the recent success it has attained with the launching of a Saturn I super-rocket. On January 29, it succeeded in putting a 17-ton payload in orbit around the earth with the aid of the huge rocket. The 17-ton payload is three times heavier than the largest Soviet manned space capsule put in orbit."

A Japan Times (Tokyo) editorial hailed the successful launching of the Saturn I super-rocket and stated that "This success has not only given the United States a temporary lead over the Soviet Union in development of rocket thrust power, but stimulated the dream of travel to the moon."

The Melbourne Age, (Australia), editorialized: "The giant rocket Saturn I has gained for America a decisive lead in the space race.... The successful Saturn firing is not an isolated achievement. It is only the first of a series in which bigger and bigger rockets will launch vehicles ultimately designed to land on the moon and return safely to earth."

U.S.-USSR: Hopes for Cooperation

Much of the editorial comment stressed the hope for cooperation in space exploration, especially cooperation between the United States and the Soviet Union.

The Manila Times editorial, "Reaching for the Moon," suggested there was more to the recent launchings than friendly rivalry. The editorial stated that:

> "The Russians could not have lofted their twin Elektron space stations just to steal the headlines from the Americans' giant Saturn metal balloon, biggest satellite ever orbited so far. Nor would the moon probing Ranger have been launched on the heels of the Saturn just so the United States could score twice in a row in the space derby.... Possibly, the United States and the Soviet Union are keeping each other posted in order to avoid needless duplication of what in the end might turn out to be a joint effort: lunar exploration by human beings.
>
> "The whole world would benefit from such cooperation, while the participants would spare themselves much anxiety, expense and possible tragedy by pooling their resources. For either of them to be the first on the moon would reduce the prestige of the other, to recover which he might have to employ other than scientific means."

In Korea, the Chosen Ilbo editorialized:

> "Ranger VI scored a triumphant first for the United States by landing at a pre-determined point on the moon.... Its successful mission...is a feat of which not only the United States but also the entire Free World can be proud.... The United States and the USSR have laid solid groundwork for materializing man's dream of making a trip to the moon. Effective United States and Russian cooperation in plans to conquer the moon would be important economically, would contribute to the realization of man's dream, and would also lead to an end of the cold war and peace for the world."

The Japan Times, following up an earlier editorial applauding the United States in launching Saturn I, noted the Russian experiment of putting two space satellite stations into different orbits from one rocket and commented: "These parallel developments remind us of the proposal made by the late President Kennedy in the United States last year. He said: 'In a field where the United States and the Soviet Union have a special capacity -- the field of space -- there is room for new cooperation for further joint efforts in the regulation and exploration of space. Include among these possibilities a joint expedition to the moon.' "

Japan's Yomiuri expressed the hope that exchange of data and other cooperation would be realized between the United States and the Soviet Union for the scientific exploration of outer space but added that such cooperation is thought to be difficult because it is largely related to military science.

The Singapore Straits Times struck a definitely negative note in its editorial. The paper contended that the chief result of the latest space success of the United States would be to put an end to its offers to cooperate with Russia in putting a man on the moon. The Times argued that, since the United States has trailed the Soviet Union for so many years in the space race, she will be less willing to cooperate now that she has the lead.

Side Issue: Space and U.S. Domestic Politics

The Straits Times also speculated that the launching of Saturn I has brought a new factor into the American Presidential election campaign. The paper noted that President Johnson has made "lavish provision" for the moon project. Paying for such a project and at the same time living up to his commitment to reduce spending are going to be difficult, according to the Times. The paper commented further that the American people are so elated over the recent space success, they will demand still more achievement. The Administration is well aware, the paper points out, "how greedily rocket research eats up money."

Side Issue: Japanese Critics of Local Program

Recent Russian and American achievements in the space field have stirred up dissatisfaction in Japan with its own proposed program. The Asahi and Mainichi, both influential Tokyo papers, expressed dissatisfaction with the space exploration program drafted by the Cabinet Space Development Deliberation Council. The Asahi pointed out that space science is linked in both the United States and the Soviet Union with military purposes. This is not true in Japan, the paper says, and therefore Japan should clarify what targets are to be emphasized in Japan's space exploration. The Mainichi deplored the fact that no plan has been made to establish a united research body to resolve the conflict of views within the council itself.

Moscow reported the launching of Echo II as the first joint Soviet-U.S. space venture with marked approval, and expressed the hope that it would be the beginning of increased scientific cooperation between the two countries.

In contrast Moscow paid little attention to either the launching of a U.S. satellite by the Saturn I rocket, or to the Ranger VI moon shot. What little commentary there was tried to denigrate the achievement of Saturn I by implying that merely putting weight into orbit was not a great scientific feat, and brushed off the Ranger shot as hardly worth comment. The Soviet space stations Elektron 1 and 2, however, were given heavy coverage, and their scientific value was consistently stressed.

Initial Reaction -- Echo II

A TASS broadcast in English reported that Echo II would be "used as a means of communication via space," and quoted U.S. news agencies who described the new satellite as a "space ambassador." A Soviet scientist was quoted as saying that "Soviet scientists like their American colleagues, regard the launching as a token of the strengthening of friendly scientific ties between our countries." Finally, Moscow expressed the hope that Echo II "would be long-lived, meet all the test objectives, and that thus the first Soviet-American space experiment would be a success." Subsequent reports described the course of the satellite and its scientific mission.

Saturn I

Moscow's initial reaction to the announcement of the January 29 U.S. satellite launching was a single broadcast over the TASS International Service in English which quoted American news agencies as saying that "the new satellite is of limited scientific importance because most of its weight is comprised of 11,600 pounds -- five tons -- of Florida sand and the burned-out rocket engines of the second stage weighing 13,500 pounds -- about six tons." Moscow reported without comment that the total weight of the satellite launched into orbit was 17 tons.

Elektron 1 and 2

On the following day, TASS announced that "a space system -- two scientific stations Elektron 1 and Elektron 2 -- was put into orbit by the USSR by one powerful carrier-rocket." The broadcast then described in detail the course of the space station and its scientific value: "The fundamental task of the launching of the Elektron 1 and Elektron 2 space station is the simultaneous studying of the earth's internal and external radiation belts and physical phenomena connected with them."

Moscow also reported that U.S. news agencies had "marked as 'urgent' and 'flash'" the reports from Moscow on the Elektron launching.

At the same time, TASS reported President Johnson's statement on the Saturn rocket without comment, but there was no evidence that it was broadcast within the Soviet Union.

Ranger VI

Moscow reported the launching of Ranger VI with the single remark that the television cameras on board were to photograph the moon's surface "if Ranger VI does not stray off the fixed course."

When Ranger VI failed to photograph the moon, Moscow devoted only two brief news items to it. One reported factually the UPI statement that "the lunar experiment has ended in failure because the television equipment did not function." The other, a TASS broadcast in English, quoted the Vice President of the British Interplanetary Society that the Ranger's failure to relay pictures of the moon's surface "is one of the most bitter disappointments of the space age."

Meanwhile, Moscow continued extensive comment on its Elektron space stations, emphasizing their scientific importance.

East European Reaction

East European comment on the latest round of satellite launchings has been minimal. In taking note of the Saturn I launching, a Czechoslovak domestic news service broadcast remarked that Soviet rocketry is "still a match for the United States." Soviet silence about the power of its own rocket boosters was attributed to military requirements.

Yugoslav reaction was limited to factual reporting of the Soviet and American launches, with the added observation that "the space race between the two countries continues undiminished."

There has been moderate coverage and favorable commentary on the recent U.S. space achievements, and virtually no reaction, other than Cuban, to the Soviet space shots. Newspaper editorials generally expressed the belief that the U.S. has surpassed the USSR in rocket thrust, and other commentaries minimized the partial failure of Ranger VI. In addition, some dailies stressed the advisability of U.S.-USSR cooperation in space exploration.

The Cuban media discounted the importance of the Saturn space shot and implied that the Soviet Union continued ahead of the U.S. in space technology as demonstrated by Elektron I and II.

U.S.-USSR: A Comparison

Lima's conservative Expreso called the launching of Saturn I "a feat which puts the United States ahead of the Soviet Union in the conquest of space [and one which should be] a guarantee for world peace." Mexico's independent Novedades applauded the "extraordinary triumph of American space science. With this happy experiment of the Saturn I the United States surpasses the Soviets. [Its 17 tons] triples the weight launched by the best efforts of the Soviet Union. This Saturn developed, in its first stage, the fantastic thrust of 34 million horsepower." The conservative La Nacion of Buenos Aires said that "whoever has followed U.S.-Soviet space competition must not be surprised with the change of tactics by the U.S. The launching now of a 17-ton satellite is not only progress, but a jump. The Americans have now confronted the Russians with the reality [that] we are already in the moon decade."

As to Ranger VI, La Nacion commented that "while we await the results of this extraordinary probe, we may affirm that contrary to what it said, the Soviet Union has not abandoned the plan to send a manned vehicle to the moon. And, perhaps, Russia is now ready to accept proposed American cooperation." According to Lima's ultraconservative El Comercio, "yesterday's felicitous launching renews confidence in the American space program." The editorial deplored the Soviet refusal to accept the late President Kennedy's invitation to cooperate and avoid duplication of expense and effort in space research. El Mercurio of Chile, in an editorial entitled "The Myths Continue to Fall" said "the image of the [Soviet] giant has been on the wane since [the first Sputnik]."

In a second editorial on recent U.S. space accomplishments, Novedades played down the failure of the television cameras in Ranger VI and emphasized the greater technical triumph of hitting the moon and even "rectifying" the rocket's direction in flight. More than half of the attempts to learn more about space have been failures, according to El Grafico of Guatemala City, and the partial failure of Ranger VI "will not be able to discourage the Americans who in one week have achieved such successes as the launching of Saturn I and Echo II." El Diario Ilustrado of Chile noted the U.S. space successes and spoke of the "free and creative collaboration of scientists, technicians, administrators and the mixture of public and private initiative" in the U.S. program, as compared to the rigid governmental control of the Soviet program which is always "surrounded with mystery and frequently accompanied by childish propaganda boasts."

Cuban Comment

Saturn I "is the most useless satellite the United States has put into space thus far," declared Radio Havana. The brief commentary said the vehicle carried nothing but junk and sand but did not give the payload weight. Radio CMQ added that the Saturn shot came after "eleven successive launching failures." The launchings of the Soviet's Elektron 1 and 2 were reported factually.

NEAR EAST AND SOUTH ASIA

Regional preoccupations in the Near East and South Asia presumably limited headline and editorial treatment of American space feats. The Soviet Elektron shot, however, appears to have received even less notice. Comment on the U.S. achievements was limited to a few Indian and Greek papers and one Lebanese paper and most of the comment dealt with Saturn I. All papers felt that the U.S. had, at least temporarily, forged ahead in space. Soviet-American space cooperation was urged.

U.S.-USSR: A Comparison

Editorial comment invariably mentioned that the U.S. was now ahead of the Russians in rocket power.

The Hindu of Madras said: "The news from the U.S. in recent days has been both encouraging and a little disappointing.... Saturn I...is twice as heavy and...the U.S. has also succeeded in landing an 800-pound spacecraft on the moon within twenty miles of a target.... Unfortunately the taste of success has been somewhat marred by the fact that the camera system failed to transmit any pictures back to earth."

Beirut's as-Safa found these recent U.S. space accomplishments "constitute a great guarantee for world stability because the world can feel more secure if technological superiority remains in the hands of the western democratic states."

In Greece, Saturn I was given good news play featuring U.S. superiority over the USSR but there were no banner headlines. Kathimerini of Athens hoped "this American success proving American leadership can result in lifting of Soviet reservations on a cooperative scheme unless the Soviet government has abandoned its space program for reasons of economy." The Economic Times of Bombay cautioned that, although the U.S. was ahead, "the Russians too may have one or two tricks up their sleeve."

U.S. -USSR: Competition and Economic Waste

The Economic Times pointed out the "crushing financial burden" the moon race involved for the two competitors, the growing criticism in the U.S. that "considerations arising from national prestige are not worth the [financial] sacrifice, and the waning enthusiasm in the Soviet Union for a moon landing. The commentator added, however, that these considerations were "apparently not near enough to eliminate national rivalries.... The developing countries would in any case be far more impressed by financial and technical aid to improve living standards on earth than by the most spectacular attempts to blaze the trail to a heavenly body above."

AFRICA

Available African media comment on the recent space shots is exceedingly light. To date, Kenya's East African Standard and the Northern News in Northern Rhodesia, have commented.

U.S.-USSR: A Comparison

The Standard (European-controlled) called the Ranger VI lunar shot "a wonderful feat of space marksmanship," which "arrived exactly on time" with its point of impact. Noting that the probe was "technically a failure" because of the inoperation of its television cameras, the Standard said "nevertheless its mathematical precision was fantastic."

The Northern News (European-controlled) in Northern Rhodesia commented that "however disappointing was the failure to obtain pictures," the flight was "a real triumph for American scientists" and shows the U.S. is "certainly not lagging behind" in the (space) race. The News added it was "a phenomenal success in many ways."

Side Issue: Interest in Space

Indicative of African interest in space developments, record crowds of students and other visitors attended several lectures by an American space lecturer at Lovanium University (Congo-Leopoldville). Interest and curiosity were reportedly stimulated by the new U.S. space achievements.

Space
Bundy

15

January 31, 1964

~~CONFIDENTIAL~~

MEMORANDUM FOR BROMLEY SMITH S

SUBJECT: Echo II and Greetings Exchanges

According to the Department, Hugh Dryden and Blaganravov have been discussing a possible exchange of messages via Echo II on February 21.

Evidently there will be a teletype exchange which Dryden would like to have with Blaganravov.

There will also be a voice exchange. And the word State has from Dryden is that the Soviets have suggested the possibility of a "high level" voice exchange without specifying who would be involved. (These exchanges will be handled between Jodrell Bank in England and Gorki in the Soviet Union because this happens to be the geometry of the situation.)

The immediate question is whether the President would want to use this opportunity for a voice exchange with Nikita Khrushchev. The exchange, of course, would be taped in advance.

There are two real problems here -- (1) whether the President wants such an exchange come February 21, and (2) what are the risks of advance taping, given the numbers and kinds of developments that could take place between the time of taping and the actual exchange.

My view is that the President might usefully take advantage of this opportunity to continue his dialogue with Nikita and to reiterate the theme of his New Year's message to Khrushchev, his reply to Khrushchev's letter of December 31, and his proposal to the Geneva Disarmament Conference. As for the possibility that international developments might upset the apple cart, it seems to me we could have a clear understanding if something untoward happened, there would be no exchanges via Echo II.

~~CONFIDENTIAL~~

8

~~CONFIDENTIAL~~

This is something the President will probably want to decide himself. In any case, we should have some word for the Department early next week.

David Klein

16

Mr Smith

Brown – the 1st.
guidance is attached.
A longer piece has
also been prepared
and is very closely
held.

1/28

[illegible]

OUTGOING TELEGRAM Department of State

INDICATE: ☐ COLLECT
☐ CHARGE TO

~~CONFIDENTIAL~~

BUNDY-SMITH
ALEXANDER
BELK
BRUBECK
CHASE
DINGEMAN
DUNGAN
FORRESTAL
JESSUP
JOHNSON
KLEIN
KOMER
SALINGER
SAUNDERS
SCHLESINGER
SMITH, WM. Y

X

12570

Space

~~Disarm~~

16a

46

Origin
DAC
Info:
SS
EUR
SCI
NASA
WHB

ACTION:

US MISSION GENEVA TODIS 1205

JAN 24 7 10 PM '64

FOSTER FROM FISHER

"Contingency statements regarding the matters you raise are now being cleared in State and NASA. No need for them is expected for several months following successful launch scheduled Monday, but they will be supplied to you when ready. In case of failure to achieve orbit, the launch trajectory will not pass over ENDC countries. Meanwhile, if approached on this subject, please refer the inquiry to State and NASA in Washington."

GROUP 4.

END

Rusk (BALL)

DECLASSIFIED
Authority Group 4
By Dut, NARA, Date 1-23-81

Drafted by:
ACDA/ST:BLBasore

Telegraphic transmission and classification approved by:
ACDA/DD:ASFisher

Clearances:
ACDA/ST - Dr. Scoville
State, SCI - Mr. Packard
NASA - Mr. Frutkin (phone)
XXXXXXXXXXXXXXXXXXXXXXXXXXXX

~~CONFIDENTIAL~~

FORM 5-61 DS-322

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

~~CONFIDENTIAL~~

16-b

RESPONSE TO QUERIES

RE: SA-5 Fragment Return Possibilities

A. Prior to any impact:

This problem has been very carefully studied. The possibility of a fragment from SA-5--or any other space vehicle--endangering human life or property, while it exists, is very remote and difficult to measure. Discussion of such an improbable incident would be heavily conjectural. The likelihood of damage is much less than that from natural meteorites.

B. After a reported impact:

Under no circumstances does this agency (government) conjecture on the origin of an object. Rather, it desires to obtain, analyze, and attempt to establish the origin of such an object.

C. After it is known that a fragment is to be delivered to us:

The object will be subjected to study and prompt public announcement will be made when analysis has been completed.

IMPORTANT:

All additional responses will be made by the Administrator, the Deputy Administrator, or the Associate Administrator. Queries requiring such additional responses should be referred to them.

Julian Scheer Assistant Administrator for Public Affairs	Arnold W. Frutkin Assistant Administrator for International Programs

January 27, 1964

~~CONFIDENTIAL~~

1472

1/24/64

17

1. ~~Mr. Johnson~~

2. Return to BKS

From NASA, ACDA and State have it in hand. Copies will be given you on Monday by NASA. [initials]

INCOMING TELEGRAM *Department of State*

W [illegible] Space X

M

Action

SS

Info

~~TOP SECRET~~

~~Johnson~~ F 17-b

CONTROL: 17625
RECD: JANUARY 24, 1964, 10:01 AM

002

FROM: GENEVA

Cy 3 dest

ACTION: SECSTATE DISTO 1503 PRIORITY

DATE: JAN 24, 3 PM

EXDIS

//~~TOP SECRE~~T//

EXDIS

FROM FOSTER

IF POSSIBILITY REMAINS OF DAMAGE BY IMPACT OF PARTS OF SATURN SURVIVING REENTRY, I WOULD APPRECIATE GUIDANCE AND/OR CONTINGENCY STATEMENTS SINCE ORBITS, BY OUR CALCULATION, PASS OVER FOLLOWING MEMBER NATIONS ENDC: BRAZIL, BURMA, ETHIOPIA, INDIA, MEXICO, NIGERIA, UAR.

GP-2.

TUBBY

EXDIS

DECLASSIFIED
E.O. 13292, Sec. 3.4
By jc NARA, Date 8-11-08

~~TOP SECRET~~

THE WHITE HOUSE
WASHINGTON

18

Mr. Bundy

Dr. Welsh brought the attached paper in. He said it is the proposal worked up by Mr. Finger, which he referred to as $150 million estimate and which may now be cut down to $149 million.

Space

DEC 17 1963

18a

Mr. Kermit Gordon
Director
Bureau of the Budget
Washington, D. C. 20503

Dear Mr. Gordon:

As we discussed on December 16, 1963, a research and technology development type of nuclear rocket program can be logically conducted at a total level below our earlier recommendation of $209 million in Fiscal Year 1965. This lower budget level is $149 million broken down as shown in the Attachment.

We believe that Dr. Wiesner's recommendation ($70 million) or even Alternative #2 in your memorandum for the President ($120 million) would essentially cancel the nuclear rocket program. We believe that rather than cancelling the program, we should maintain a continuing effort which includes sufficient reactor and engine testing to permit us at some future time to undertake the development of nuclear rocket propulsion systems that will be needed in the space program.

This alternate program is proposed by NASA and the AEC because of the importance we attach to nuclear rockets in our space exploration program and because of the high priority we assign to providing research information and technology in this important area. We urge that a strong and continuing program is essential in this important area to establish the background of information needed to provide a basis for engine system development and advanced space mission planning.

Such a program would have the following benefits over the Alternative #2 that you proposed to the President and over the budget level proposed by Dr. Wiesner.

1. It would permit the conduct of a continuing reactor research and engineering program aimed at providing reactor technology for the

power levels, temperatures, operating times, and operating cycles required for the various missions for which nuclear rockets would be used.

2. It would permit us to assemble and test reactors with turbopumps, nozzles, and suitable control systems into ground test engine configurations to establish a base of information on the design and operating characteristics of nuclear rocket propulsion systems.

3. The technical results of 1 and 2, above, would permit advanced mission planning to consider the use of nuclear rockets and would permit us to undertake the development of a nuclear rocket propulsion system at any required power level when such development is required for mission applications.

4. The technical competence and organizations that have been established to conduct work in this area would be retained, providing the flexibility of increasing the level of support to proceed into engine development when such development is considered necessary.

5. The proposed program is a continuing level of effort program that would proceed at about the same budget level as in Fiscal Year 1965 for several years, but would decrease in later years if engine development were not undertaken.

6. The proposed program would have the full support of both NASA and AEC in Congressional hearings as a sound technical effort aimed at providing the technology needed for the accomplishment of advanced missions in space.

This alternate program anticipates work on thousand megawatt reactors as a logical, technical stepping stone to the development of higher power reactor systems (Phoebus). It plans on bread-boarded engine system work at the thousand megawatt level as a convenient and significant size in establishing the operating characteristics of nuclear rocket engines. It does not plan on testing the many sets of hardware planned in the original $209 million program until engine system development is required for mission use.

The proposed program differs substantially from the program that was recommended by NASA and AEC at the $209 million level. Although that program accepted the cancellation of RIFT until such time as successful reactor operation was achieved and missions could be defined more clearly than is now the case, the NERVA engine work covered in that program eventually involved full flight propulsion system development. Logical growth in that kind of a flight engine development program would require that budget levels in Fiscal Year 1966 would be substantially increased above the $209 million level recommended for Fiscal Year 1965.

As we indicated in our earlier letters to you on the subject, your Alternative #2 essentially cancels the nuclear rocket program. Your alternative does not provide for engine system evaluation such as has been found to be essential in establishing the technology of all new propulsion systems; it does not provide enough information to form the basis for eventual nuclear rocket flight system development; and it would not provide the data required to permit advanced mission planning based on the use of nuclear rocket propulsion systems. The presently recommended program would provide this needed information.

The budget level proposed by Dr. Wiesner would immediately cancel all system work and engineering work on the reactor and would continue purely an inhouse laboratory research effort. A program at that level could not provide meaningful technical information. It would disband the competence that has been established for work in this area. It could inhibit this country's ability to undertake nuclear rocket development at any time. As a result, the efforts and $420 million already expended could have been essentially in vain. Such a program would end the nuclear rocket effort.

Although the proposed program would involve a reduction in staff level at Aerojet of 675 direct and indirect people, at Westinghouse of 200 people, and approximately 200 people at other locations, the total effect on employment would be significantly less than the reduction of a total of 3800 people involved in your Alternative #2 or in Dr. Wiesner's proposal.

Under the program we propose very few new facilities beyond those already available or under construction in Nevada would be required.

It would not be necessary to expend construction funds already appropriated to NASA in Fiscal Years 1962 and 1964 in the amount of $14,150,000 and $12,410,000, respectively, for nuclear rocket work.

If you need any further details on this program plan, please call us. We will, of course, be happy to participate in any further discussions that are necessary on this program.

Sincerely yours,

James E. Webb

James E. Webb
Administrator
National Aeronautics and Space Administration

Glenn T. Seaborg
Chairman
Atomic Energy Commission

OFFICIAL USE ONLY

ALTERNATE NUCLEAR ROCKET PROGRAM
(in millions of dollars)

AEC		
KIWI (ground prototype reactor)		0
NERVA Technology		48.0
Advanced Systems		28.0
Graphite	24.0	
Tungsten and all other	4.0	
Support of NRDS		8.0
GSO		-2
Equipment		6.0
Facilities		3.0
		91.0
NASA		
KIWI		0
NERVA Technology		35.0
RIFT		0
Supporting Research & Technology		23.0
Support of NRDS		0
Facilities		0
		58.0
Total Program		149.0

OFFICIAL USE ONLY

19

THE WHITE HOUSE
WASHINGTON

December 13, 1963

MR. PRESIDENT

I have just learned that the Saturn flight discussed in the attached memorandum has been postponed for at least a month due to technical difficulties. Consequently the matter is not urgent. Nonetheless, the problem will still exist when the flight is rescheduled.

JBW

Space

19a

THE WHITE HOUSE

WASHINGTON

December 13, 1963

MEMORANDUM FOR

THE PRESIDENT

I should like to call your attention to a question that has arisen in connection with the December 18 first launch of the Saturn C-1 vehicle.

In the experiment it is planned to put a dummy payload consisting of 1200 lbs of Jupiter nosecone, 13,600 lbs of sand and miscellaneous other parts into an orbit having a minimum altitude of 140 nautical miles. In a period of time estimated as anywhere between zero and 340 days, it will re-enter the earth's atmosphere and most of it will be burned up and dispersed. However, calculations predict that roughly 1000 lbs of the residue will remain in the form of fairly substantial pieces; possibly there could be thirty or forty fragments having weights in the vicinity of thirty pounds or so. Unfortunately, there is currently no way to control, or even accurately predict, where the pieces will impact, so that there is a finite probability of damaging property and even killing someone. NASA calculations indicate a probability of about one part in 50,000 of hitting a person, and a somewhat larger chance for impact on a building. It is estimated that there is one chance in twenty that impacts will occur in an inhabited area (such areas being defined as those with a population density of more than fifty persons per square mile).

It should be noted that such hazards have always been associated with space satellite launchings, though the fragments from prior U.S. launches have been considerably smaller than those expected from the Saturn rocket. We believe that several Soviet launchings have resulted in as much earth residue material as is predicted for Saturn. Secretary Rusk and to a certain extent Mr. McCone are concerned about this problem, largely because they believe that a mishap could have serious political repercussions which would adversely affect the Space Program and, perhaps lead to other political difficulties as well.

However, the only remedial action we could take at this time would be to shut down the motors on the Saturn vehicle before it reaches orbital velocity, thereby causing it to follow a ballistic trajectory and to land in the ocean. NASA feels that doing so would reduce the value of the flight test, and I agree, though I think the flight would still be useful even with the associated loss of information. Because this problem will arise with increasing frequency in future flights, I believe we might as well face the question now.

In my opinion the risks are sufficiently small that the test should be permitted as planned. I have expressed this view to Secretary Rusk and Mr. McCone. Mr. McCone stated that he was merely reflecting the Secretary's concern since this was not an area of his responsibility. The Secretary has asked that I notify you so that you are personally aware of his concern about this problem. As a result of our conversations, Secretary Rusk is somewhat, but not completely, reassured.

JBWiesner

Jerome B. Wiesner

20

1.
Mr Bundy ✓ BKS
2. CY

FYI

Jerry Wiesner has
talked to Rusk.
CY

C E Johnson Space
File

December 10, 1963

20a

Dr. Jerome B. Wiesner

Dr. Donald Steininger

Safety probabilities relative to SA 5 test.

In SA5 the Saturn I will put into orbit its second stage (SIV) and a dummy payload which consists of 13,600 lbs. of sand and a 1200 lbs. Jupiter nose cone. Total weight in orbit is 38,000 lbs. Other characteristics are:

Orbit perigee and apogee: 140 n mi. x 345 n mi.
Lifetime: can be anywhere between 0 and 340 days with nominal of 148 days
Orbital inclination: 31.6°.

To determineprobability of a person getting hit by a decaying fragment, NASA obtained services of Lockheed to analyze the reentry to determine number and size of fragments and area of dispersion; and NRL to calculate probabilities. The results of the Lockheed calculations are summarized in the attachment and seem reasonable.

The probability calculation made the following assumptions:

1. There is an equal probability of a fragment impacting anywhere between +31.6° and -31.6° of latitude.

2. Of the total population between these latitudes, 1/3 are asleep and therefore under cover and, of those awake, 2/3 are under cover. Therefore, 2/9 of total population is exposed.

3. Even distribution of exposed population.

The probability calculations compared the total area offered by exposed persons and the area of impacting fragments with total area of earth between +31.6° and -31.6°; and the probability of getting hit by one fragment was multiplied by the number of fragments. This resulted in the probability of hitting a person of 2 in 100,000.

If an inhabited area is defined as an area having population density of 50 persons/sq. mi. (Kansas has 25), then NASA finds that about 5% of the total area between +31.6° and -31.6° falls in this category. So the chances of the fragment group falling on such an area is about 1 in 20.

Although I did not check the arithmetic of the calculations, I cannot find fault with the method or the assumptions.

The following observations seem pertinent:

1. All future earth orbital tests using the Saturn I and Saturn IB will leave a similar stage in earth orbit. The only way to avoid this is to add altitude control mechanisms and retro rockets to the stage. This increases weight (which NASA maintains cannot be accommodated) and complexity; and would require about 2 years and $3 to 7 million to develop. NASA maintains this would mean a considerable delay in the program. This argument seems reasonable.

2. The Soviet Union in their Vostok launches place a stage in decaying orbit about the same size as that we are now considering.

3. Present routinely acceptable safety probability at AMR is 1 in 100,000. There have been many occasions when waivers have been permitted by AMR for higher probabilities, and in several instances as high as 1 in 700 over Cuba. (The latter information is from NASA and I have not yet been able to verify it.)

4. Although not formally announced, the forthcoming launch of the large payload, has been anticipated by the press. It would seem unwise to cancel because we consider safety problems too great, when we face acceptance of similar risks in many future tests.

5. The calculations are conservative because:

   a. The actual probabilities are such that impact along 31.6° latitudes are more probable than along equator. (This means greater probability of landing on water than was assumed.)

   b. All areas were treated as being of equal political concern. If selected areas of particular concern were picked out, and probabilities calculated, the chances of impact and injury would be much lower.

6. NASA has done its best to reduce hazard, for example by using a sand payload, and perforating the Jupiter nose cone so that it will be destroyed during reentry.

Finally, the only immediate remedy to the situation for SA5 if probabilities are unacceptable, is to cut off engines before orbit. NASA says the following information is desired and would not be obtained:

1. Precision of orbital velocity.

2. Determination of tumbling rates (NASA says this information will be useful for SA6 which will have a micrometeorite payload).

Although the value of these from a technical standpoint may, perhaps, be questioned, a more important consideration, in my opinion, is the fact that in future tests requiring orbit we will face the same risks.

I believe that we should recommend to the Secretary of State that these risks should be considered as not unusual and to be necessary if present Apollo program is to proceed on schedule. Since there are so many assumptions necessary in the calculation of these probabilities, it would be useful for Mr. Rusk or his representatives to talk again to the NASA people and specify areas of concern. If, for example, only a few areas are of real concern to the Secretary, then the probabilities above would not apply and actual probabilities would no doubt be much less.

DHS/ems Chron
JBW Chron
S&T File
S&T Chron