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MASTER

SNAP 8 POWER SYSTEM
FOR THE
GLOBAL SURVEILLANCE SATELLITE

GROUP I

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GLOBAL SURVEILLANCE SATELLITE

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Prepared By
ADVANCED REACTOR DEVELOPMENT DEPARTMENT

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SUMMARY

It is proposed that the electrical power required for the Global Surveillance Satellite (GSS) be supplied by a modified SNAP 8 nuclear power system. SNAP 8 is a 30 electrical kw system that is currently under development by Atomics International, as reactor contractor to the USAEC, and by the Aerojet-General Corporation, as power conversion equipment and system contractor to the NASA. It will be flight-tested in early 1965. SNAP 8 will offer a light weight, reliable, and rugged system, of proven feasibility, that is compatible with all the GSS requirements. If the GSS power requirement should be increased above its presently estimated 24 kw peak load, the SNAP 8 system offers the advantage of scale-up to 60 kwe with only minor modification to the system.

The modified SNAP 8, as it will be installed in the GSS vehicle, is shown in Figure 1. During operation it will be extended 30 feet from the tail of the vehicle as shown in Figure 2. Extension of the nuclear power supply from the vehicle during operation is desirable since it results in a large reduction of shield weight.

A system schematic is shown in Figure 3. The reactor is cooled by a liquid metal, sodium-potassium eutectic (NaK), which transfers the reactor thermal energy to the mercury working fluid in a compact boiler. The superheated mercury vapor is expanded through a turbine and is passed to a condenser where it transfers its heat of condensation to an organic fluid, Dowtherm A. The Dowtherm is pumped to the radiator, located on the underside of the wings (Figure 2), where it radiates the waste cycle heat to space.

The entire power system weighs 6750 lb. A weight breakdown is given in Table I.

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Figure 1. Modified SNAP 8 Power Supply

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Figure 2. Power Supply Installation in GSS Vehicle

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Figure 3. Flow Schematic of Power System

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TABLE I

WEIGHT SUMMARY OF SHIELDED POWER SUPPLY

	<u>lb</u>
Core, Reflector, and Controls	392
Boiler	102
Primary NaK Pump	16
Primary NaK Liquid	58
Primary NaK Reservoir	12
Primary NaK Piping	5
Structure Within Containment Vessel	10
Condenser	70
Subcooler	30
Turbine	14
Alternator	45
Power Line	40
Miscellaneous Electrical Items	80
Mercury Inventory	42
Hg Pump	2
Hg Reservoir	15
Hg Piping	20
Organic Liquid	150
Organic Pump	20
Organic Reservoir	20
Organic Piping	200
Radiator	100
Structure	250
Extension Mechanism	100
Insulation (Thermal)	<u>12</u>
Total Unshielded Weight	1805
Tungsten Shield	2568
Lithium Hydride Shield	1215
Boron Steel Shield (containment vessel)	<u>1162</u>
Total Shield Weight	<u>4945</u>
Total System Weight	6750

CONCEPT SELECTION

A nuclear power supply is chosen for the GSS for its light weight, high reliability, operational simplicity, flexibility, and relative ease of integration and compatibility with mission requirements. Table II summarizes the present estimate of the satellite's power requirements ⁽¹⁾:

TABLE II
GSS POWER REQUIREMENT

Peak Load	24.0 kw for 14 min/orbit
Standby Load	9.6 kw for 77.8 min/orbit
Average Load	11.8 kw

Single or Multiple Turbogenerators

The power system designer has the option of using either a single turbo-generator or multiple, smaller units to convert reactor heat to electric power. Unquestionably, the larger single unit will be lighter. For example, the SNAP 8 turbogenerator is designed for 30 electrical kw at a weight of 71 lb, ⁽²⁾ while the smaller SNAP 2 unit produces 3 kw and weighs 45 lb.

The argument could be advanced that multiple small units offer higher reliability than a single large unit. This conclusion would have to be based on an operational analysis, for while the chance of producing some power may be greater with multiple units, the probability of producing design power is reduced. For the mission power profile given in Table II, it would seem that if the power output dropped from 11.8 to 9 kw, for example, there would be power available only for the standby load, and the ability to perform the useful part of the mission may be entirely lost. Further, if one generator of four 3 kwe units, for example, were to fail, it would require rather complex sensing and switching devices to accomplish the changeover to the reduced power demand. This, of course, could be done but at the expense of system simplicity and hence reliability.

Peak or Average Power

Another choice open to the power system designer is whether to produce peak power continuously, or to produce the average load, satisfying the peak requirements by electrical storage batteries.

There are several reasons for continuously producing peak power. One is the current state of development of the SNAP 8 turbogenerator. This system will be available for use in the GSS with no separate development program as would be required to design and perfect a single 12-kw turbogenerator. Furthermore, a system which produces peak power actually will be lighter than the average power case. For example, the entire SNAP 8 power conversion assembly, exclusive of radiator, weighs 455 lb. If the power supply were to produce the average load of 11.8 kw, electrical storage of 2850 whr would be required. If nickel-cadium batteries with a rechargeable storage capability of 10 whr/lb and a depth of discharge of 50% were used, 570 lb of batteries would be required, or more weight than the entire power conversion system. Incidentally, 50% discharge at 10 whr/lb represents a considerable advance over present state-of-the-art.⁽³⁾ The decision to produce peak power is thus justified by reason of availability and weight. An additional point that must not be overlooked is that the SNAP 8 design point is 30 kw. If the GSS power requirement should be increased, SNAP 8 can provide up to one-third more peak power than is presently called for, with no major design changes. Of course any increase in the standby load of 9.6 kw, up to 24 kw, is there for the asking. The utilization of this additional available power should be thoroughly investigated in terms of increasing mission capability and relaxing design restrictions on power-consuming equipment.

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SYSTEM DESCRIPTION

Introduction

The development of SNAP 8 started in the spring of 1960 as a joint NASA-AEC project. The current program objective is flight test in 1965.

The basic SNAP 8 30-kw nuclear turboelectric power supply consists of a zirconium hydride reactor heat source, a liquid metal loop with associated pump and expansion tank to transfer heat from the reactor to the boiler, a once-through boiler, a mercury-driven 30-kw turboalternator, and a condenser to reject the waste cycle heat. The reactor is being designed with the thermal capacity to operate two of the basic 30-kw generators for a total power output of 60 kw. In the basic SNAP 8 design the condenser radiates its heat directly to space; for the GSS system the radiative condenser has been replaced by a compact condenser which transfers the heat of condensation to a third liquid loop containing Dowtherm A. The Dowtherm is circulated through the radiator, where it rejects heat to space.

After the mercury is condensed, it is passed through a small radiator where it is subcooled by about 240°F. The subcooled mercury provides a low-temperature bearing and alternator lubricant and coolant.

Reactor Description

The reactor and control system assembly are shown in Figure 4. The reactor fuel and moderator are contained in cylindrical rods of uranium-zirconium hydride clad with Hastelloy N. The rods are bundled and held in place by top and bottom grid plates. The entire assembly is contained in a stainless steel core vessel, 9-3/16 in. in diameter and 20 in. long.

Reflector Control System

The reactor is controlled by movable, 3-in. thick beryllium reflector, consisting of four rotating elements and two fixed pieces. At launch, all four elements are held out, away from the core, putting the reactor in its most unreactive configuration for safety. After an orbit has been established, two of the elements are driven in rapidly

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Figure 4. SNAP 8 Reactor

by a spring. Then the third element is driven in slowly by a gas-bleed drive causing the reactor to go critical and reach a low power level. The fourth element is driven by a reversing stepping motor which is activated by temperature sensors on the outlet coolant line. This system actively controls the reactor over the rest of its life.

The support frame for the reflector assembly will be made in two halves so that under scram conditions the two halves spring apart, completely separating from the reactor. Scram may be actuated by an active signal, re-entry heating, or reactor cool-off (end of life shutdown).

The characteristics of the reactor and control systems are summarized in Table III.

Power Conversion System

The basic SNAP 8 power conversion system consists of the following major components and subsystems⁽²⁾:

- a) A shell-and-tube boiler, which transfers thermal energy from the reactor coolant to the mercury working fluid.
- b) A primary loop, reactor coolant, mechanical pump. The pump circulates the NaK from the reactor through the boiler and back to the reactor.
- c) A multistage, pressure-compounded, axial-flow impulse turbine. It is mounted on a common shaft with the alternator and mercury pump, and driven by mercury vapor.
- d) A brushless, electromagnetically excited, six-pole alternator, having dual, three-phase, series-connected stators.
- e) A combination jet-centrifugal mercury pump.
- f) Miscellaneous devices to regulate system startup and to control voltage and frequency over the operating lifetime.

In addition, the SNAP 8 system has a radiative condenser which radiates the latent heat of the condensing mercury directly to space. Since, however, large pressure drops in condensation lead to reduction in condensing temperature

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TABLE III
SNAP 8 NUCLEAR SYSTEM CHARACTERISTICS

Operating Conditions

Reactor thermal power	300 to 600 kw
Net electrical power	30 or 60 kw
Outlet coolant temperature	1300°F
Inlet coolant temperature	1100°F
Operating Pressure	25 psia
Operating life	10,000 hours
Maximum fuel temperature	1456°F
Maximum cladding temperature	1405°F
Maximum fuel thermal stress/ultimate tensile strength	12,000 psi/25,000 psi

Reactor Design

Fuel elements

Number	211
Diameter	0.560 in.
Length	14-1/4 in.
Fuel	Zr - 10 wt %U, Hydrided to $N_H = 6 \times 10^{22}$ atom/cc
Cladding	10 mil Hastelloy N
Spacing between elements	10 mil

Internal reflectors

18 Hastelloy N clad BeO
fillers

Lower grid plate

3/8 in. Hastelloy C

Upper grid plate

11/32 in. 316 stainless steel

Core vessel

Internal diameter	9-3/16 in.
Length	20 in.
Thickness	1/16 in. 316 stainless steel

Reflector control elements

Number	4
Material	Beryllium
Thickness	3 in.

Weight, including core vessel and controls

392 lb

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and therefore must be avoided, it would be unreasonable to try to bring the mercury through flexible lines back to the wings of the vehicle, which offer the best available source of radiator area. The basic SNAP 8 system has been modified by condensing the mercury in a compact heat exchanger which is located in the extended reactor package, as shown in Figure 1. After the mercury has been condensed, it is passed through a small (25 ft²) radiative subcooler which is located on the outside surface of the shield vessel.

The heat of condensation is removed by an organic fluid, Dowtherm A, which is circulated through the radiator and back to the condenser.

The radiator surface is the lower wing surface. The Dowtherm is circulated through niobium tubes, which form an integral part of the wing honeycomb structure. The procedure in Reference (4) was followed in performing the radiator analysis. Details of the radiator and condenser design are given in Table IV.

Mechanical Design

The power system is designed to be rugged, light-weight, and easily removable from the vehicle. For this reason, the reactor and entire primary coolant loop are enclosed in a steel containment vessel. The vessel is designed to contain all dangerously radioactive material in case of a mishap. Any pressure up to 5000-lb/in.² can be contained by the 1-in. thick vessel.

The reactor and other items requiring shielding are compacted into a small volume around which the shield is placed. The reactor is located behind as much material as possible in order to take advantage of the shielding effect of the material. The containment vessel is made of boron steel for shielding purposes. Gamma attenuation is accomplished by the use of a W-Ni-Cu alloy, while lithium hydride is used for neutron absorption. A sizeable part of the heat developed in the shield will be developed in the heavy shield materials; that is, the steel vessel and the tungsten alloy. For this reason, cooling tubes are placed in the shield at this position. Cooling is provided by passing the organic heat transfer liquid through the tubes. The hydride is supported in position by a structure that totally encloses the material so that it does not dissociate in the vacuum of high altitude. The tungsten alloy used as a shielding material also acts as the internal structural members for the system.

TABLE IV
RADIATOR AND CONDENSER DESIGN DETAILS

RADIATOR

Radiating Surface	10-mil niobium, coated with emissive coating
Surface Emissivity	0.9
Surface Area (Total)	420 ft ²
Radiation Effectiveness	0.75
Tube Material	Niobium
No. of Tubes	250
Tube Spacing	1.44 in.
Tube Dimensions	1/8-in. OD, 10-mil wall, 13.8 ft long
Tube Weight	78 lb*
Manifold Weight	22 lb
Fluid Pressure Drop	10 psi
Geometry	2 panels, one in each wing - 14 x 15 ft

CONDENSER

Tube Side Fluid	Condensing Mercury
Tube Details	30, stainless steel, 3/8 inch-OD, 22-mil wall, 8.77 ft long
Heat Flux	40,500 Btu/hr-ft ²
Condensing Pressure Drop	3 psi
Shell Side Fluid	Dowtherm A
Maximum ΔT	140°F
Minimum ΔT	50°F
Shell Side Heat Transfer Coefficient	450 Btu/hr-ft ² -°F
Tube Weight	22 lb
Shell Weight	48 lb

*This does not provide for a meteoroid barrier. An additional 60 mils of niobium in front of each tube would provide a meteoroid non-puncture probability of 0.995 over the mission life, according to the method of Ref 4. This would weigh an additional 200 lb.

Integration

The nuclear power supply is located in the extreme tail section of the vehicle during launch. The reactor package is extended 30 ft from the vehicle during operation, in order to reduce shielding weight. The importance of this separation is demonstrated by the fact that the shield is lightened by over 3400 lb by extending the reactor package 30 ft instead of operating it in the vehicle. Additional distance between the reactor and vehicle would lighten the shield even more. The determination of the proper separation distance involves a trade-off between shield weight and weight of the extension system. This trade-off cannot be completely accomplished until the maneuver requirements of the vehicle are more firmly established.

All major components of the system are extended with the reactor, except for the radiator, which is integral with the wing structure of the vehicle. The radiator consists of two panels, one on each wing, shown as dotted lines in Figure 2. Flexible lines carry the organic liquid from the mercury condenser, mounted on the reactor package, to the radiator and back.

The reactor package is attached to the extension rods and flexible tubes in such a way that it can be ejected from the vehicle at any time. The structural support for the reactor package is sufficient to allow the vehicle to land with the package in the retracted position in case this becomes necessary. In this case, the reactor package could be easily removed from the flight vehicle by a shielded ground vehicle, so that manual operations around the flight vehicle could be performed.

The mechanism used for extending and retracting the reactor package is shown in Figure 5. It consists of two hollow extension members, 32 ft long, that are driven fore or aft through the hollow shafts of an electric motor. The extension members are threaded outside and driven by nut-screw action. Unwanted turning is provided by a spring actuated, friction brake.

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Figure 5. Extension Drive Mechanism

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SHIELDING

Sources of Radiation

At the altitude of the GSS, the air density is so low that the dose rate due to air scattering will be negligible. Thus, the dose rate in the crew compartment will be entirely from direct radiation and structural scattering.

In the shielding calculations the following sources were considered:

- a) Direct core fast neutrons,
- b) Direct core gamma rays,
- c) Structure-scattered fast neutrons,
- d) Structure-scattered gamma rays.

Preliminary calculations indicated that the scatter shield weight was much more than the direct shield weight, when equal dose rates are received at the crew compartment. As a result, it was decided to design the shield so that 80% of the dose rate in the crew compartment would be from structure-scattering. Furthermore, it was arbitrarily decided that half of the dose rate would be from gamma rays and half from neutrons. It should be mentioned that this is not necessarily the optimum relationship between direct and scattered radiation, or between gamma-ray and neutron dose.

The source strength used in the shielding calculations is that of the SNAP 3 core at 300 thermal kw. The dose rates at 50 ft from the unshielded reactor are 6.53×10^3 rem/hr from gammas and 1.76×10^3 rem/hr from neutrons (RBE ~10).

Method of Calculation

The core fast neutron dose rate was calculated assuming that the core is a point source. Core self-absorption was accounted for by methods given in Ref. 5. Removal theory was used in a single exponential attenuation kernel. The neutron source strength was corrected to account for neutrons above approximately 4.0 Mev only.

The core gamma ray dose rate calculation was also based on a point source. Core self absorption was accounted for by the same methods as above. The core gamma ray source strength was assumed to be 17.0 Mev/fission, all carried by 3.0 Mev photons.

The scattered neutron and gamma ray dose rate was calculated using the SCARF-1 code⁽⁶⁾. This code is a computing aid for shielding problems involving spacecraft powered by SNAP reactor systems. It provides a first order approximation of the fast neutron and gamma ray dose rate at the crew compartment due to scattering of neutrons or gamma rays from radiator fins, or in this case, the flat wing structure. Differential scattering cross sections for fast neutrons were obtained from Ref. 7, and Klein-Nishina differential scattering cross sections were used for gamma rays. For scattering calculations the wing was considered to be iron with an area density of 6.7 lb/ft^2 . This density corresponds to the total wing weight of about 8000 lb for the GSS. The scattering properties of iron are close to those of niobium and Rene'41, the major constituents of the wing.

Attenuation by Equipment

In the direct core fast neutron and core gamma ray calculations, attenuation due to equipment located between the reactor core and the crew compartment was considered. It was assumed that the density of the equipment is 5.0 lb/ft^3 (8), and that it extended 40 ft from the rear of the crew compartment to the front of the reactor compartment. This gave an attenuation of a factor of 10 for the core fast neutrons and 40 for core gamma rays.

Permissible Radiation Dose

While no permissible radiation dose for manned space flight has yet been fixed by any government agency, current thinking in the NASA and Air Force is that a dose of about 5 rem for a "routine" space flight is permissible, with 25 rem possible under emergency conditions.⁽⁹⁾ Therefore, the shield design specification is for a total integrated dose of 5 rem during the GSS mission, or 5 mrem/hr. It should be noted that the shield reduces the dose rate from the reactor by more than six orders of magnitude, so that if the allowable dose rate is changed by a factor of 2 or 3, it will have little effect on the shield weight.

Radiation Dose During Re-Entry

As the vehicle enters the earth's atmosphere, air scattering of the reactor radiation will become significant. Based on a decay period from orbital shutdown to sea level of two hours, the dose rate at sea level in the crew compartment will be 250 mrem/hr. Since the time required from re-entry (100,000 ft)

to sea level is only five to ten min⁽⁸⁾, the crew will receive less than 40 mrem from air-scattered radiation during this period.

Details of Shield Design

Figure 6 shows the details of the required shield. Shielding material is placed on the sides of the reactor package only in the direction of the major radiation scatterers, that is, the wings and fuselage. Cooling tubes containing Dowtherm pass through the shield to remove the 6 kw or so of heat generated by neutron and gamma-ray absorption. For the reactor extended 30 ft from the vehicle, the calculated shield weight is 4950 lb, of which 2570 lb is tungsten, 1220 lb is lithium hydride, and 1160 lb is the steel reactor containment vessel.

Possible Means of Reducing Shield Weight

As mentioned before, the shield weight may be reduced by extending the reactor package farther from the vehicle. Extension by an additional 30 feet (to a total of 60) may reduce the shield weight by about an additional 1000 lb. One further method of lightening the shield is the use of rocket fuel as shielding. The GSS vehicle will have about 3000 lb of fuel at the beginning of re-entry⁽⁸⁾. Certainly, this material can be aptly located so as to provide the maximum possible amount of shielding. Such problems as containment of the rocket fuel, thermal environment, and possible radiation damage, remain to be studied.

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(MEASUREMENTS IN INCHES)

KEY

/// BORON STEEL

XXXX TUNGSTEN ALLOY

REMAINDER OUTSIDE CONTAINMENT
VESSEL — LITHIUM HYDRIDE

EXTENDED SHIELD

Figure 6. Shield Detail

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Startup and Steady-State Operation

SNAP 8 is currently being designed to provide for remote startup in orbit and operation for one year, completely unattended.^(2,10) In a manned system, modifications will be made in this procedure to permit control of startup and operation by the men on board. No study of these modifications in procedure has yet been made.

Shutdown and Reactor Disposal

After the reactor has been shutdown at the end of mission (full power operation at 300 kw for 6 wk) a decay period of approximately 1 hr will be advisable prior to reactor coolant flow shutdown and re-entry from orbit. The fission product inventory and decay heat are shown in Figures 7 and 8 as a function of time after shutdown. After one hour decay, the fission product inventory will be approximately 5×10^5 curies and the total fission product decay heat will have been reduced from 5.7 to 2.5 kw. During the period of return from orbit the decay heat will raise the reactor temperature by less than 225°F/hr. Such a temperature rise will not damage the reactor core nor cause release of the fission product inventory.

Several methods of reactor disposal are possible after the end of the mission. The following possible reactor disposal methods are listed in their order of preference, from a purely safety standpoint, with a discussion of the advantages and disadvantages of each method.

1. Release and Propel Reactor Core Into Sun

The safest method of disposing of the radioactive reactor core would be its release and disposal into the sun. Such operation presents no handling, storage or disposal safety problems to hamper the disposal procedures. The disadvantages include the reliability of placing the reactor core in the proximity of the sun for destruction. If the reactor core were to be released and unsuccessfully propelled toward the sun, control of the re-entry path and consequently of the radioactive source would be lost. Re-entry burnup and high altitude dispersal would not necessarily occur under such conditions, thus causing a radiation hazard. The major disadvantage, of course, is the technological incapability of performing the task of propelling the reactor core from orbital velocity to the velocity necessary for impact on the sun. The weight necessary

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Figure 7. Fission Product Inventory and Dose at 1 Meter after Reactor Shutdown

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Figure 8. Fission Product Decay Heat after Shutdown

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in fuel, rockets and auxiliary equipment would be incompatible with mission requirements at this time or in the near future.

2. Release and Propel Reactor Core Into Long-Lived Orbit

The method of allowing the radioactive reactor core to decay while in orbit to a radiation level considered insignificant prior to re-entry is also an attractive method from a safety standpoint, as well as for disposal procedures. Since the initial orbit for the mission will be short-lived (low orbital altitude), one would need to release and propel the reactor core into a higher and, consequently long-lived orbit. Although successful completion of such a disposal procedure would seem to have definite advantages, the disadvantages associated with such a method are similar to the method in which the reactor core is released from the plane and propelled into the sun.

3. Reactor and Shield Release From Plane Into Disposal Area

Another method that will allow maximum safety and minimum disposal procedures would be release of the reactor and shield as a unit from the re-entering plane into a radioactive waste disposal area. The re-entering plane would then be able to land at any available airport under normal landing procedures dictated by the vehicle itself. The basic disadvantage of such a method is the development of a release system which is reliable and which can land the reactor and shield unit within a reasonable radioactive waste disposal area. The disposal area might be the same area that is used for disposal of bombs from a malfunctioning aircraft. One advantage of this method is the removal of a large amount of weight from the tail section of the plane, thus simplifying the problem of vehicle attitude control.⁽⁴⁾ Further details of this disposal method are presented below.

4. Landing of Plane With Reactor and Shield on Board

Another method of disposal would be landing of plane with reactor and shield remaining on board. Although control of the radioactive sources will be maintained as well as containment of said sources within a known area, the possibility of error, fission product release, contamination, and radiological hazards due to a crash is greatly increased due to the large number of landings contemplated. The breach of such safety contingencies could endanger the landing area, the facilities, the usefulness of such landing areas and the facility personnel. Possibility of danger to the general population would be remote for

these cases. The protection of the plane crew would, however, become more difficult. In addition, the safety procedures would be difficult to perform and the inventory of radiological equipment on standby during landing would necessarily be extensive.

5. Re-entry Burnup of Reactor and High Altitude Dispersal of Debris

The least feasible method for reactor disposal from low altitudes (~300,000 ft) would be re-entry burnup of the reactor and high altitude dispersal of the debris. Two disadvantages of this disposal method are present in the missions planned. The basic area of concern is the feasibility of destroying the reactor by re-entry heating at such altitudes and still retaining adequate altitude for dispersal of the debris. In previous re-entry burnup analyses, an altitude of at least 300,000 ft was necessary to burnup and disperse individual SNAP fuel elements. In the case of the missions planned, the individual fuel elements would have to be released from the reactor core while the plane was still in orbit. Even then, the angle of re-entry for the individual fuel elements might be altered sufficiently so that re-entry heating would not destroy and disperse the fuel elements. Also, the number of returning vehicles, i.e., one per week, would be large enough to cause a significant increase in the atmospheric fission product inventory with concomitant future concern of biosphere contamination. In all respects, the dumping of radioactive wastes into the atmosphere should not be encouraged if other means of disposal are possible, more feasible, and create less radiological hazards.

Typical Shutdown and Disposal Procedure

A typical shutdown and disposal procedure which could be followed after completion of a 6-wk mission at 300 thermal kw is outlined in the following operational steps.

Step 1

The reactor will be shutdown at the end of mission and prior to return from orbit. The coolant system will continue operation for one hour after power shutdown of the reactor to remove afterglow heat and prepare plane (reactor system) for return from orbit. After one hour cooling time, the reactor and shield will be returned to the plane and prepared for the return trip. Such preparations will include absolute reactor shutdown under all return conditions, e.g., impact on

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surrounding media. The reactor will be secured, and reactor and shield placed in position for disposal by crew.

Step 2

Plane will be "maneuvered" from orbit and into pre-planned return flight path by combination ground control and plane crew. Once satisfactory return flight path is established, control of plane is to be assumed by ground command station. During the initial deceleration, the plane crew will not participate in landing procedures except in emergency. The plane crew can be ejected at any time during return flight and returned safely.

Step 3

At an altitude of approximately 60,000 ft, the flight path will be leveled and a glide path established for landing at a given landing field. Plane crew will prepare plane for release of reactor and shield over the radioactive waste disposal area. The radioactive waste disposal area will lie along the flight path and 25 to 30 mi from the landing field.

Step 4

At an altitude of approximately 20,000 ft and 25 to 30 mi from touchdown, the plane crew will release the reactor and shield as a package from the plane. The reactor and shield package will be released over the radioactive waste disposal area and lowered into this area by parachute for a soft landing.

Step 5

The plane will land at the landing field under normal landing procedures. No additional landing precautions will be necessary since the plane will not contain any radioactive material or nuclear reactor. Upon successful completion of landing procedures, a cold clean reactor and nonradioactive shield will be installed in preparation for the next mission.

Step 6

The radioactive shield and reactor will remain in the radioactive waste disposal area for a minimum time of six months. After a 6-mo cooling time the package of reactor and shield may be removed for processing.

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The reactor core may be reprocessed to recover the unused fuel while the remainder of the package may be removed for radioactive waste burial. The possible areas of radiological hazards during these procedures are outlined below.

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SAFETY PROCEDURES

Pre-launch

During the period from shipment through integration of the SNAP reactor system, the reactor will be shutdown by means of mechanical lock-outs on the reflector system. The radioactivity in the reactor due to acceptance tests will be in the millicurie range. The radiation level present outside the containment vessel surrounding the reactor and shield configuration will be less than 1 mr/hr. Such radiological conditions are necessary for safety of handling, integrating and preparing the vehicle for launch by personnel and plane crew. The containment vessel will present a barrier to release of fission products and to addition of a hydrogenous media around reactor. Such a barrier is a secondary safety precaution to prevent accidental criticality of the reactor during the pre-launch-through-orbit procedures. The reactor system will remain inert until reactor startup is initiated by plane crew in the predetermined orbital altitude for the mission. Additional radioactivity will not be produced except under accidental criticality of the reactor.

Launch

As during the pre-launch procedures, the reactor will remain shutdown during launch. The reactor will be started after the predetermined orbit has been established. Reactor startup will be performed by the plane crew. The radiation due to radioactivity in the reactor will be negligible during the launch period.

Assuming that a launch abort occurs or is necessary, the reactor and shield package will be destructed to ensure that criticality does not occur due to an abort condition. The plane crew may be ejected at any time during the launch phase as a group in the crew capsule. In case of a launch abort in which the reactor configuration can not be destructed, the containment shell surrounding the reactor and shield will be capable of withstanding the heat of the resulting fire or an impact force due to terminal velocity fall. The reactor core is being designed to remain subcritical if immersed in water. Emergency safety procedures will include normal missile launch exclusion areas, protection for launch personnel and stand-by equipment for reactor recovery, fire fighting and decontamination of launch site and/or impact area.

Mission Operation

During reactor startup in orbit, the plane crew will follow routine reactor startup procedures, and precautions used in similar SNAP 8 reactor startups will be practiced. The instrumentation will be typical for reactor operation. Special safety features such as capability of releasing reactor and shield package during the mission and ejection of plane crew anytime during mission will be included. The total integrated dose that may be received by any crew member during the mission will not exceed 5 rem in six weeks of operation. Radiation monitors and alarms will be available to warn the crew member of any malfunction in the reactor system.

Reactor Shutdown

At the end of mission, the reactor will be shutdown for one hour prior to return to base. The reactor will be shutdown in such a manner that reactor operation cannot be initiated again; i. e., an irreversible scram will be initiated. After one hour cooling time during which the coolant will continue to remove the afterglow heat, the reactor and shield package will be returned to the plane and coolant flow stopped. At this time, the crew will close coolant line valves so that these lines can be disconnected in preparation for release of reactor and shield package from plane during return flight. The reactor and shield package will then be prepared for the return flight and properly oriented for release from the plane at the designated time in flight.

Re-entry

During the return flight from orbit to approximately 60,000 ft the operation of the plane will be under ground control. In case of malfunction during this period, the crew may be ejected at any time and returned to earth safely. The reactor and shield package may also be ejected if such action will assure that the radioactivity contained within the package can be safely disposed of in this manner. If such assurance cannot be determined under these emergency conditions the reactor and shield package will remain with the plane and emergency teams detached to the area of impact to perform necessary radiological protection procedures.

Under normal flight procedures, the crew will prepare the reactor and shield package for ejection during the 60,000 to 20,000 ft flight path duration.

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At 20,000 ft, the radioactive package will be ejected and lowered into the pre-determined radioactive waste disposal area by parachute. Although high reliability of such a system is possible, safety precautions must be taken in case of malfunction. If the parachute does not open, the containment vessel surrounding the package will be capable of withstanding the impact upon the disposal area terrain at terminal velocity of the package. If the ejection system does not function properly to release the package, the plane may land at an alternate emergency field providing such action can be performed. Under normal flight procedures, the radioactive package will be released into the disposal area and the plane will land under normal landing procedures at the prescribed airfield in its flight path. The crew will leave the plane under normal conditions and the mission will be completed.

Reactor and Shield Disposal

After the radioactive package has been released into the disposal area, a minimum decay time of six months will be allowed before recovery of the package is attempted. After six months decay, the fission product inventory will have decayed to a level of 6×10^3 curies and a gamma dose rate of 50 r/hr at one meter for an unshielded reactor core, as shown in Figure 7. Using shielded carriers, the entire package can be removed from the disposal area and processed in a suitable hot cell. If recovery of the uranium fuel is considered advisable, the reactor core can be removed from the package and reprocessed for use in future reactors. The remaining radioactive package, i.e., shield, auxiliary equipment and containment shell, will then be transferred for either land or sea burial. If the reactor core is not reprocessed, the fuel elements may be removed and also transferred for burial. The total activity of each fuel element would be approximately 30 curies with a gamma dose rate of approximately 100 mr/hr at one meter.

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DEVELOPMENT PLAN

The system proposed is a modification of the SNAP 8 power unit currently under development jointly by the AEC and NASA. The present development schedule for the SNAP 8 system is shown in Figure 9. It is assumed that this program will proceed according to the schedule and that a fully flight-qualified SNAP 8 system will have been demonstrated prior to the initial flights of the GSS system. Hence, the amount of development work required for the proposed system is considerably reduced and consists mainly of system integration, shield development, and demonstration of the final configuration. It is anticipated that such a program could be accomplished in approximately four years assuming the availability and use of the SNAP 8 facilities. It is thought that only two nuclear systems would be required for this development program. One would be a ground prototype system to prove out the final selected shield design and configuration. The second system would be operational, and would be available for early flight tests of prototype vehicles. The cost of these two systems would be approximately 4 million dollars. Additional costs for the design and integration studies, shield development, and non-nuclear systems tests would run approximately 6 million dollars and would be accomplished over a four year period. This brings the total cost of the development and demonstration of this system to about 10 million dollars.

The cost of follow on production models would run approximately 1.5 million dollars for the complete system, in quantities in excess of five units. Figure 10 summarizes the recommended development schedule for adaptation of SNAP 8 to the GSS.

SNAP 8 Development Plan (as currently funded by AEC-NASA)

The major steps in the SNAP 8 development program are illustrated schematically in Figure 11.

S8ER

The first major step is the SNAP 8 Experimental Reactor (S8ER) which is now being fabricated for operation in April, 1962, without power conversion equipment. The objectives of this test are to demonstrate the reactor design point performance at 600 kw of thermal power and 1300°F NaK outlet temperature, and to measure the performance characteristics of the reactor.

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Figure 9. SNAP 8 Development Schedule

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Figure 10. Development Schedule for GSS Power System

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Figure 11. SNAP 8 Reactor Development Plan

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Component Development

While the S8ER is being built, the flight reactor components are being developed to withstand the launch and space environment. This component development work is directed towards fuel elements, core structure, reflector control and safety mechanisms, automatic startup and control circuitry, and the shield.

Ground Prototype

The second test reactor is designed to be a flight reactor. It is to be based on results from the component development work and on operating data from the experimental reactor. Two reactors of this design are built; one enriched and one un-enriched. The enriched reactor is used in the 30 kw ground prototype system which is composed of flight components including reactor and power conversion system; however, the components are arranged in a breadboard configuration for easy access and maintenance. This test has two objectives:

- 1) To obtain developmental information on the overall system performance characteristics, particularly on automatic startup and control; and
- 2) To demonstrate the performance and endurance of the flight reactor.

The ground prototype system will be tested in the facility which is being designed by an A&E for the AEC with construction to be completed by October, 1962.

Environmental Test Reactor

The un-enriched reactor of the same design as the ground prototype is subjected to environmental tests to demonstrate that the reactor will withstand the launch conditions and will operate satisfactorily in the vacuum environment of space.

Flight Prototype

The third enriched reactor is the same as the ground prototype reactor except for modifications indicated by the ground prototype test or the environmental tests. This reactor is used in the 30-kw flight prototype test which demonstrates the complete SNAP 8 system in the flight configurations.

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Delivery Items

The final step in development of the 30-kw system is the flight test launched by NASA in March, 1965. Two enriched reactors and two mockups are required for this test. The first mockup is a simple non-working model which approximates the size and weight of the reactor. This so-called structural mockup is used by NASA to test the vehicle structure. The second mockup is a copy of the flight reactor with working parts and instrumentation except that it contains dummy fuel elements. This inert reactor is assembled into the flight vehicle for checkout of the complete vehicle system. Shortly before launch the inert reactor is removed from the vehicle and one of the two live reactors is installed. The other live reactor delivered for flight is a spare.

NASA has indicated that the 30-kw system may be followed by development of a 60-kw system. At NASA's request, both the reactor and the nuclear test facilities are sized for the 60 kw system. Although NASA has not yet authorized development of the 60 kw system, one possible 60 kw program is described here for planning purposes. After completion of the 30 kw ground prototype system test, the system could be made into a 60 kw ground prototype by adding a second turboalternator and radiator to the original 30 kw system. Following this test, a 60 kw flight prototype system could be tested in the flight configuration facility after the 30 kw flight prototype system has been removed. This approach would lead to flight test of a 60 kw system about one year after the 30 kw flight test.

The 30 kw program includes five enriched reactors; the experimental reactor which goes critical in April, 1962, the ground prototype reactor which goes critical in July, 1963, the 30 kw flight prototype reactor which goes critical in April, 1964, and the two flight test reactors, the first of which will be launched in March, 1965. The 60 kw program described above would require three additional enriched reactors: The 60 kw flight prototype reactor and the two delivered for flight test.

Development Status

During FY 61 a conceptual design of the SNAP 8 reactor was completed using design features and experimental data from the SER and the S2DS reactors. Basic data on fuel burnup, hydrogen retention, and materials compatibility were extended to the temperature and power density required in the SNAP 8 core.

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Hydraulic experiments were carried out to adjust the coolant flow distribution in the reactor core to the required flow profile. The design of the S8ER was nearly completed and fuel fabrication and procurement of long lead time components was initiated. The SER reactor and NaK system were removed in preparation for installation of the S8ER. Component development for the flight core, reflector, controls, and shield were initiated.

The two major goals to be accomplished in FY 1962 are (1) to complete and successfully operate the S8ER and (2) to design, fabricate, and test each each of the components required for the flight reactor.

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