SNAP 2 SYSTEM AND VEHICLE INTEGRATION*

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Abstract

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

I. Vehicle Design Considerations

A Nuclear Auxiliary Power Unit, herein called NAPU, offers many advantages to the missile designer for the longer lived satellite and space probe missions. SNAP 2 for example furnishes 3 kw of well regulated electrical power with a system weight of approximately 750 pounds unshielded or about 1050 pounds shielded (this is highly dependent on vehicle design as is shown later). This corresponds to about 4 watts per pound or, on an energy basis, some 40,000 watt-hours per pound. There is no sun-shadow transient and no orientation problem such as is associated with a solar unit. Integration of the nuclear APU into a vehicle is straightforward if the designer is familiar with the characteristics of the nuclear system. Unfortunately, very little information now available in the open literature is of any great use to the designer. Since such information is vital to the ultimate utilization of a NAPU, the following discussion will present some of the considerations which may lead to a good design.

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*Presented at the Space Power Systems Conference, Santa Monica, California, September 27-30, 1960. Work done under AEC Contract: AT(11-1)-GEN-8

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In the previous papers on SNAP 2, specific attention had been given to the Reactor Heat Source, the shield, the Power Conversion System and the Heat Rejection System. The focus will now be placed on the integration of the above subsystems into operational satellite vehicle applications. A fundamental criteria of the NAPU is for operation both on the ground under conditions of 1 g, and in space under conditions of so-called "zero g." The above consideration is particularly important with respect to the relative position of the mercury pump inlet and the mercury liquid level. Other NAPU component characteristics must also be considered. The mercury flow pressure drop from the turbine exhaust, through the condenser, to the mercury pump inlet must be minimized for reasons of optimum system performance and of prevention of pump cavitation. Pressure head limitations of the NaK induction type pump necessitate minimization of all NaK system flow pressure drop (i.e., reactor core, boiler, orbital pump line heater and expansion tank). Finally, design objective for all NAPU components is that of operation in a 600°F environment without the aid of auxiliary cooling.

The overall installation of the Reactor Heat Source System and Power Conversion System with the Heat Rejection System plus the necessary startup and control systems must be carefully coordinated with the overall vehicle layout and installation. Basically, the major problem areas of such an overall integration can be listed as follows:

1) Shape, mass, and dimensional limitations
2) Nuclear shielding requirements
3) Structural loads and launch environmental conditions
4) Orbital startup
5) Hazards.

In achievement of the optimized APU system and configuration, necessarily certain compromises between all the above factors must be resolved.

The first major criteria to be established is the NAPU location contour and dimensional restrictions. The problem presented to the designer concerns the APU location with respect to other components of the vehicle system. There are many ramifications to this choice of location that must be considered before an optimum design can be obtained. For example, the reactor shield combination is the heaviest component in the NAPU and may vary from a minimum of 300 to 500 pounds for an optimum vehicle arrangement with a radiation resistant payload; through 700 to 800 pounds for an optimum vehicle with a conventional transistorized payload;

to 1200 to 2000 pounds for an inept vehicle-payload arrangement. Vehicle design will be simplified in most cases if this mass is located on the vehicle thrust line, although in some specific instances other heavy components in a vehicle may be used as counter balances. The above restriction will normally prevent location of the reactor-shield combination in the propulsion section of the vehicle since tanks, pumps, and thrust chambers usually preclude center line locations.

In general, two locations are of a particular interest, although many variations are possible. The two examples shown in Figures 1 and 2 will be used to demonstrate the effects of vehicle arrangement. Figure 1 shows a "modular" design with a payload nose cone, a cylindrical NAPU section and a propulsion section. Figure 2 indicates a NAPU "nose cone" installation with a conical radiator, a payload section which may be initially nestled within the radiator, and a propulsion section. In either case the propulsion section may be jettisoned in orbit. Each of these systems has advantages and disadvantages which will be discussed.

Structural scatter of nuclear radiation emitting from the reactor can cause a high payload dose if shielding for the scattered radiation is not used. In the case of the modular design, with conventional transistorized payloads and no separation of the payload section from the remainder of the vehicle, the shield weight will be 900 pounds or greater depending on the payload frontal area. However, if a radiation resistant payload is used, for example, one utilizing hard tubes or especially selected transistors in circuits which are tolerant of noise and component performance drifts, the required shield weights in this configuration may only be some 250 pounds.

If the reactor is located in the vehicle nose and the nose cone fairing is jettisoned as shown in Figure 2, and if the payload is extended back below the radiator, an optimum shield results. The reactor and shield are on the vehicle thrust line and no structural scatter occurs since the entire vehicle-payload complex is within the shadow of the shield. With a conventional transistorized payload of any practical volume, the shield weight will be 400 to 500 pounds.

It was shown that the payload tolerance affects the shield weight a great deal. It has been assumed that a conventional payload utilizing transistors can be subjected to 10^{12} nvt of fast neutrons and 10^{7} r of gammas. A payload especially designed for NAPU's would utilize hard vacuum tubes and radiation resistant transistors in especially designed circuits which are tolerant of component drifts. Such a payload could be expected to withstand greater than 10^{14} nvt and 10^{9} r. Extremely radiation sensitive payloads, i.e., photographic film, should be equipped with individual shields so as to raise their tolerances to the payload design value.

The nose cone layout does introduce disadvantages, however. The APU is about 13 feet long instead of 7 feet as in the modular design. Of course the possibility of nestling the payload within the radiator exists in this layout whereas the modular layout precludes this. The NAPU access on the launch pad is better with the nose cone location but payload visual access in orbit may be much worse unless the propulsion system is jettisoned. Placing the reactor shield combination at the tip of the vehicle increases gravitational restoring torques for satellite applications but can perturb the vehicle flight stability. The "nose-cone" installation probably will also require greater basic vehicle structural capability. The "modular" installation introduces the problems of passing wiring and piping connections through the NAPU which essentially is a large welded can. Re-entry burnup of the reactor is more easily obtained with the exposed nose location.

In general, the vehicle designer may find that the modular concept is easiest to integrate into the vehicle where nose cone payloads are desirable, but, if weight is an important consideration, he may have to provide special radiation resistant payloads or utilize the nose location. Table I summarizes the two installations.

Table I

NAPU Configurations

	Modular	Nose Cone
APU weight	780 lb	750 lb
Shield weight Normal - large volume payload	$\sim$1000 lb	$\sim$300 lb
Shield weight Normal - reduced volume payload	$\sim$500 lb	$\sim$250 lb
Shield weight Radiation resistant payload	$\sim$250 lb	100 lb
Length of APU	7 ft	13 ft
NAPU access	Fair	Good
Payload access	Good	Fair
Re-entry burnup	Difficult	Accessible

Once the configuration, general installation and payload radiation sensitivity have been selected, then the detailed design is initiated on the nuclear APU. As mentioned in an earlier paper, the integral radiator-condenser acts as the primary APU structural member. If an established vehicle is modified for a NAPU, it may be necessary to conceal the radiator within the vehicle until orbit is reached, then ejecting the vehicle skin. This could be brought about by the use of a specialized plastic or cellular skin. If the NAPU is integrated into the vehicle design early in the development, it would be possible to combine many of the functions of vehicle support, space radiation surface, and aerodynamic skin. A substantial weight reduction may be so gained.

Minimization of all APU induced momentum and angular effects is a primary objective. In the case of an earth satellite, the axis of the CRU will normally establish the pitch axis of the vehicle. It, therefore, may be necessary to have a very accurate alignment between the CRU axis and the vehicle. Allowable deviations in vehicle attitude will be reflected as rpm tolerances on the CRU and as allowable torques resulting from other angular momenta in the vehicle. At low altitudes, it may be feasible to obtain attitude control from natural restoring torques or from an oscillation damper. At very high orbital altitudes, a dynamic attitude control will probably be necessary. In that case, a joint vehicle-APU study must be made so as to establish optimum induced torque specifications to the NAPU supplier. All momentum created by the NaK and mercury coolant fluid flows are purposely balanced against each other in the yaw and roll axes.

The SNAP 2 with the CRU aligned to the vehicle pitch axis system has the following estimated characteristics influencing altitude stability.

Moment of inertia of CRU	0.0013 ft-lb-sec^2
Roll axis angular momentum	$<$ 0.01 ft-lb-sec
Pitch axis angular momentum	3.00 ft-lb-sec
Yaw axis angular momentum	$<$ 0.20 ft-lb-sec

A frequency drift of 1% per year corresponds to a torque of 17.8×10^{-10} ft-lb. A shaft acceleration of 1 radian/sec^2 corresponds to 13×10^{-4} ft-lb.

Orbital startup of the APU will considerably reduce the associated nuclear hazards since reactor operation will not be initiated until a safe satellite orbit can be established. Automatic startup in orbit most certainly will not be easy to accomplish. Collection of the mercury fluid and achievement of adequate mercury pump inlet pressure appears to be the major problems. Preheating of the system plus controlled reactor power startup can be achieved through an automatic sequential controller. However, there are several feasible concepts which are being currently evaluated. Of prime importance is the selection of that startup method which is the lightest and most reliable.

Ground handling equipment and launch pad complex modifications for the nuclear APU are extremely minor if orbital startup is utilized. Telemetry for the startup must be supplied. Straightforward "go-no-go" checkout instrumentation will be available. No nuclear checkout at the launch pad would necessarily be anticipated; this could be covered in the acceptance test procedure before delivery. The APU as designed is capable of non-nuclear ground operation checkout using electrical power to supply the 50 kw of thermal power. This allows great flexibility for pre-launch checkout of the system without the inconvenience of nuclear radiation.

If a pre-launch nuclear startup is desired, the system would be brought to power using a small 50 kw electrical line heater built into a primary coolant loop. The power conversion equipment would be checked and the payload transferred to the NAPU electrical output. The reactor would be checked at very low power and then, just before launch, taken to full power as electrical heat is removed. If the mission is scrubbed, the NAPU or the entire final stage (depending on the separation provisions) must be placed in a shielded storage pit. A cleanup crew should also be available in case of a destructive booster abort.

A nuclear ground startup complicates the APU development, testing, and launch pad handling. Safety exclusion radius must be provided and blockhouse shielding assured (both of these are usually covered by safety measures normally taken due to booster chemical hazards). In general, orbital startup provides the lowest cost NAPU in terms of APU development costs and launch facility costs but with a sacrifice in reliability that may increase mission costs. Ground startup does provide 100% checkout of the system prior to launch; however, operation through the launch phase must be assured.

A final problem area to be resolved is the APU checkouts, installation and pre-launch checkout procedures. Adequate safety devices will be developed which will insure no possibility of reactor criticality. These reactor safety devices must be removed just prior to actual launch. The mercury and NaK afford no unusual hazards as long as the piping or containment is not ruptured by rough handling.

A major goal of many missile designers today is the design of a completely indestructible re-entry body. In the case of SNAP 2, the opposite is desired. Complete burnup of the reactor at extreme altitudes would effectively eliminate the re-entry hazards problems. Present plasma-arc investigations indicate that this objective can be met. It is necessary however, that the vehicle designer keep this in mind and insure that the reactor is subjected to maximum re-entry heating.

For the case of space probes and very high orbits (in excess of about 600 miles), there is no re-entry problem since there is ample time available for fission product decay before it does return. If in these cases, the designer chooses orbital startup, the overall hazards problem is essentially no different than it would have been if he had chosen any other power source.

A tabulation of the SNAP 2 component weight objectives are given in Table II for the nose cone installation.

Table II

Weight Objectives - Nose Cone Installation

Reactor	250 pounds
Boiler	100
Radiator condenser	150
Combined rotating unit	50
Miscellaneous	100
Orbital startup equipment	100
Unshielded System	750
Shield	300
Shielded System	1050 pounds

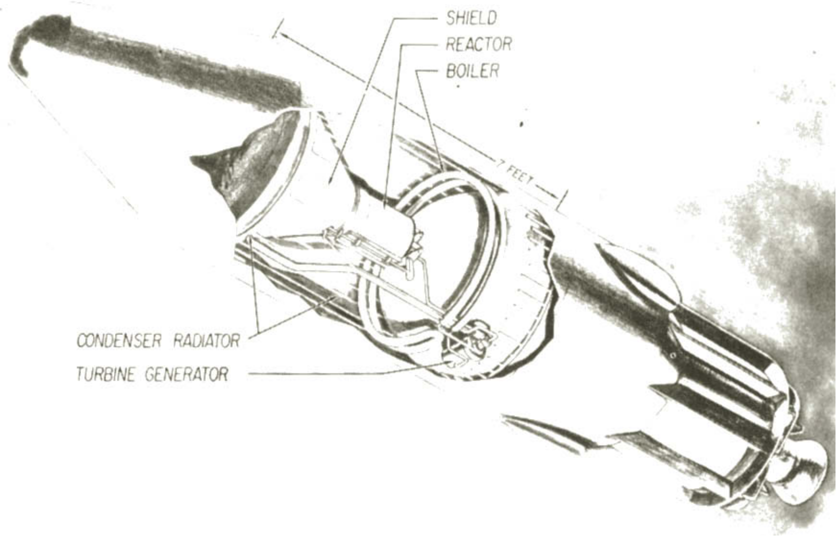

Fig. 1. SNAP 2 APU (modular installation)

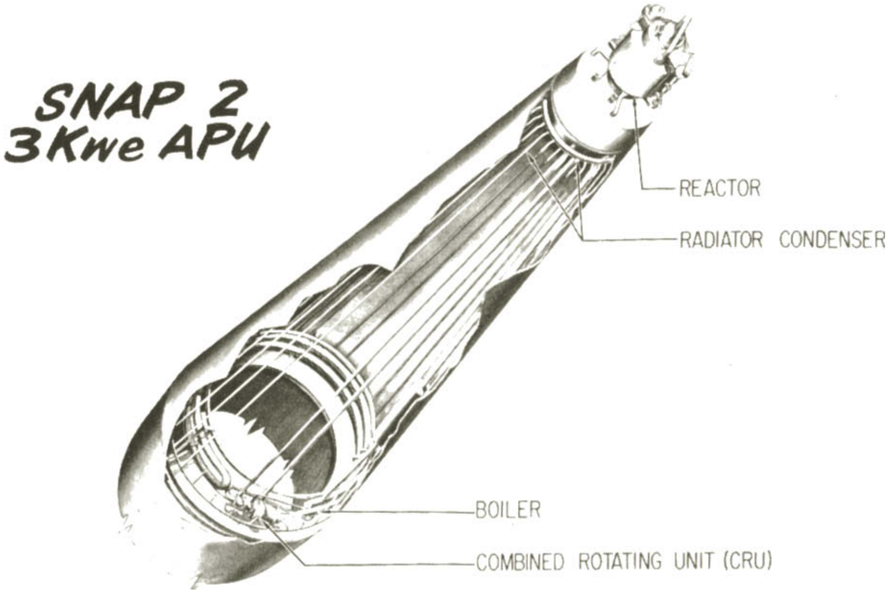

Fig. 2. SNAP 2 APU (nose cone installation)