FSEC-NSG-217-73/27
Revision A

APPLICATION OF NUCLEAR POWER
TO THE
DEFENSE NAVIGATION SATELLITE SYSTEM (DNSS)

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December 20, 1973

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Summary and Conclusions

The solar-powered Defense Navigation Satellite System (DNSS) as currently planned, is extremely power limited by virtue of the tight launch weight constraint imposed by booster-economics considerations.

Substitution of a nuclear-powered spacecraft results in significant simplification of the overall system, and, based on state-of-the-art RTG systems, can increase the end-of-mission power available for RF input from approximately 120 to 230 watts, within the booster weight limits. This can be increased to over 600 watts within the same envelope of weight and volume, and ultimately to over 1000 watts by the application of advanced-technology thermoelectric systems in later phases of the DNSS program. These advanced systems are currently candidates for development for use in the USAF SurvSatCom mission.

I. Summary of the Problem

The Defense Navigation Satellite System (DNSS) is designed to provide navigation information (position and velocity) to any suitably-equipped receiver anywhere in the world. The active portions of the system consist of satellites and ground stations. The satellites will fly in 12-hour orbits at 63-degree inclinations in three orbital planes, separated by 120-degrees. Approximately 8 satellites will occupy each plane. There will be a master ground station and a number of other ground stations to monitor the satellites and update their ephemeris and clock data. Users will be equipped with receivers, mini-computers, and read-out devices. Users can select equipment of varying cost and complexity, depending on accuracy and type of information needed.

DNSS is supposed to upgrade existing military navigation capability in three significant ways:

1. continuous global coverage
2. greater accuracy and more information
3. availability to small mobile users, e.g., aircraft, tanks, and ground forces

Item 3 requires that enough power be radiated by each satellite to be received and interpreted by small non-directional (0 db) user antennas.

Because of the large number of satellites involved, the Air Force plans to limit their launch costs by using the existing inventory of Atlas-F boosters. Within the weight constraints of this booster, Aerospace Corp. has estimated the total prime solar array power at 300 W., within a weight budget of 195 lb. (including power distribution and control). This allows only approximately 120 W of input power for the RF section at end-of-mission (EOM), which is ^{said to be} said to be extremely marginal.

The use of solar arrays in these orbits within the tight weight constraints of the Atlas F, will require a fully-oriented solar-array system. This leads to a minimum-weight array, but to a complex and high-weight attitude control system (ACS).

II. Advantages of a Nuclear Spacecraft

The major advantages of a nuclear-powered DNSS can be summarized as follows:

1. Eliminates batteries.
2. Permits simpler and lighter attitude control system.
3. Delivers more RF power with state-of-the-art technology.
4. Permits power growth as advanced technology is proved; within weight and volume envelopes originally defined.

Each of these points is vitally important and will be discussed separately.

1. Batteries

The relatively flat power profile of the DNSS payload matches the constant output power of a nuclear power system, thereby permitting the elimination of batteries. This has several beneficial advantages apart from the obvious weight and charging-power savings: The tight temperature-control requirements of the batteries generally result in the provision of battery heaters or other active temperature-control systems which consume prime power and compromise system reliability; the battery charge controllers generally also consume measurable electric power in the regulator circuits; the batteries and associated

control systems are typically the least reliable components of the electric power subsystems; the weight and power dissipation of the conducting cable connecting an extended solar array, the battery charge controllers, and the batteries, can be significant.

2. Attitude Control System

Freeing the spacecraft from the need for solar-array pointing introduces the possibility of some less complex form of attitude control. The possibilities which have been briefly examined are:

- 1.) gravity gradient
- 2.) bias-momentum wheel
- 3.) body-spinner

Each of these offers some advantages and disadvantages. The first is simplest and lowest in weight. A possible disadvantage is that the oscillations of the spacecraft will cause periodic power fall-off at the edges of the RF beam which may be unacceptable in a power-limited system. Another potential disadvantage is the requirement to move the spacecraft position at least once during the mission. A gravity-gradient-stabilized satellite might not provide sufficient attitude-control for this maneuver.

The biased-momentum-wheel approach offers the possibility of holding to closer attitude tolerances than a gravity-gradient design without introducing the complexity of full three-axis control.

A spinner satellite offers the stabilization advantages of a bias-momentum wheel, plus several other interesting advantages; e.g.:

- 1.) simpler thermal control
- 2.) simpler attitude sensing and control
- 3.) fewer reaction-control thrusters

Each of these advantages is translatable into a power and/or weight advantage which more than over-balances the small power consumption and weight of the added rotary joint. The advantages of a spinner are well-known;

its major disadvantage for this orbit with a solar-powered spacecraft, is the basic impossibility of using a body-mounted solar array: In a 63-degree orbit, the sun angle relative to a vector normal to the array varies between 63 and 86.5 degrees for half the year, thus barely illuminating a body-mounted array during this period. The use of a nuclear power system obviates this disadvantage, while retaining the other advantages of the spinner.

In summary; the nuclear spacecraft permits the choice of either a gravity-gradient, bias-momentum, or body-spinner attitude control system, as well as the 3-axis approach probably preferred by the solar array system.

No preference among these possible alternatives can be expected as a result of this highly preliminary study. However, each of these was explored for its integration aspects in a nuclear-powered DNSS.

3. Configurations

Figure 1 shows a configuration for a gravity-gradient stabilized satellite. This design utilizes an Organic-Rankine power system, with the system radiator acting as the skin of the spacecraft, at a temperature of 105⁰F. All equipment is mounted on the inner walls of the radiator structure, thereby maintaining equipment temperature within very narrow limits regardless of sun angle or equipment dissipation. This is known to be a low-weight design approach from previous studies on commercial communications satellites.*

The major disadvantage of this design for this application is the one noted above concerning gravity gradient systems.

Figure 2 shows a biased-momentum spacecraft designed for spin-injection. In this approach the Perigee Kick Motor (PKM) and the Apogee Kick Motor (AKM) are 180 degrees opposed. This eliminates the need to precess the spinning spacecraft 180 degrees between perigee and apogee, thus saving perhaps 5 pounds of payload weight. Once in orbit, the satellite is de-spun, the momentum wheel is spun-up, and the antennas are deployed. Thereafter, propellant expenditure for reaction-control is expected to be

(* report to be published early in 1974)

minimal, as the yaw and roll axes are dynamically stabilized. Propellant weight savings is conservatively estimated at 10 pounds. In addition, the ACS is estimated to be at least twenty pounds lighter than for a three-axis-stabilized solar-powered satellite.

This spacecraft is powered by two Radioisotope Thermoelectric Generators (RTG's) located around the periphery of the PKM, as shown in figure 2. The PKM is jettisoned following its use, so that little radiation blockage would result once the system is emplaced in orbit.

Figure 3 shows the spin-stabilized version of the nuclear DNSS. In this design the PKM and AKM are aligned, thereby requiring the 180-degree precession prior to AKM burn. The two RTG's are located on the "top" face of the spacecraft. The rotary antenna feed and motor are located between them, suitably insulated from RTG radiator heat. This top-mounting location permits a greater choice of RTG external envelope shapes, including the familiar finned cylinder. The bottom-mounted RTG's shown in figure 2 would be restricted to variations of the "slab" RTG design currently favored by RTG designers for low-cost advanced systems.

The advantages of the spinner previously listed are expected to be realized, with concomitant savings in power and weight. The weight breakdowns for the Aerospace solar-powered design, the nuclear spinner and the nuclear biased momentum designs are shown in Table I. For sub-systems in which no significant changes are anticipated, the Aerospace numbers were used without investigation.

As can be seen from Table I, a significant weight savings can result in other subsystems and in other parts of the electric power subsystem as a result of using nuclear power. Savings in harness weights are usually realized as a result of eliminating the harness from the extended solar array, and in power and charge control as a result of eliminating battery charge regulators and heater power regulators for battery heaters and other heaters.

The housekeeping budgets for the different designs are compared in Table II.

The nuclear powered satellites are likely to result in housekeeping power savings as shown. Further savings are likely to result, at least in the spinner design, when thermal control power is taken into account. However, the Aerospace numbers included no power allowance for thermal control.

Finally, combining these results, the power available for RF input may be compared, as shown in Table III.

Both solar and plutonium-fueled nuclear systems are compared in several technology states, within a calendar which estimates the availability dates of the various systems. As can be seen, the state-of-the-art nuclear system (1.5 W/lb EOM) delivers only slightly more prime power than the comparable solar system, and slightly less prime power than a violet-cell solar system. However, the power available for RF input is significantly greater from the nuclear system than from either solar system, because of the reduced housekeeping power requirements shown in Table 2. For the more advanced versions of both power systems, the nuclear advantage is even larger.

For the advanced solar power system, the nickel-hydrogen battery at 16 watt-hours per pound is assumed, together with violet cells with 22% greater EOM efficiency than the assumed standard cells. No adjustments were made to the housekeeping power numbers for the advanced systems although the battery charging power and other parasitic power dissipations are likely to increase proportionally with prime system power.

The advanced nuclear systems are based upon the use of selenide thermoelectric material, which is expected to approximately double the conversion efficiency of thermoelectric generators. This material has been under development for several years under AEC sponsorship, and is judged by the AEC to be ready for incorporation into generator designs. Two specific-power figures have been assumed, based on recent design studies conducted by an AEC

contractor: the first-generation selenide systems at 3.3 watts per pound, and an improved selenide system at 5.0 watts per pound. Design approaches with even large specific-power have been identified by the contractor, but minimum cost rather than minimum weight was the major objective of the design study. The study was aimed at satisfying the system requirements of the USAF SurvSatCom mission.

An important point with regard to either of the advanced nuclear systems, is that they would be designed to substitute for the State-of-the-Art system with essentially no change in spacecraft weight, volume, or dynamic characteristics. The same cannot be said for advanced solar array/battery systems.

In conclusion, the nuclear-powered DNSS is seen to result in substantial and significant increases in RF input power, even with State-of-the-Art RTG systems. Advanced-technology RTG systems can substantially improve on this capability without the need for spacecraft re-design or re-qualification.

Table I. Weight Breakdowns, LBS.
DNSS Spacecraft

Subsystems	Solar	Nuclear	
		Spinner	Biased Mom.
Payload & Antenna	128	148*	128
T & C	46	46	46
Thermal Control	10	10	10
Structure	132	132	132
ACS	75	38**	55
RCS	46	18**	46
Propellant	45	45	35
Spacecraft Adapter	50	40	40
Nuclear Hardening	40	40	40
Contingency	55	55	55
Sub-Total	627	572	587
Atlas-F throw wt.	822	822	822
Balance for Elect. Pwr. Sys.	195	250	235
<u>EPS:</u>			
Harness	40	20+	20+
Pwr. & Chg. Control	15	5+	10+
Solar Array	50	—	—
Battery	65	—	—
Balance for Nuclear Syst.	—	225	205

* includes bearings, motor, rotary coupling, and antenna mast

** based on solar-powered synch-orbit spinner designs

+ based on Fairchild studies of commercial communications satellites

Table II. Power Comparisons,
Watts (e) (Average)

Subsystem	Solar	Nuclear	
		Spinner	Bias. Mom.
T & C	32	32	32
Thermal Control	—	—	—
ACS	30	20	20
RCS	10	3	10
EPS			
Battery charging	42	—	—
Harness	9	5	5
Pwr & Chge Cont.	15	5	5
Contingency	42	42	42
Total Housekeeping	180	107	114

Table III. Solar vs Nuclear Power
Comparison on GPS Spacecraft
End-of-Mission Power, Watts(e)

Solar Spacecraft			Year Available	Nuclear Spinner		
Technology (Array/Battery)	Prime Power	RF Input Power		RF Input Power	Prime Power	Technology
Silicon/Ni-Cd	300	120	1974	230	338	Si-Ge or Pb-Te RTG
Violet/Ni-Cd	360	180				
			1976			
Violet/Ni-H ₂	530	350		630	740	First Generation Selenide RTG
			1978			
				1010	1120	Improved Selenide RTG
			1980

Figure 1. Gravity-Gradient-Stabilized DNSS

Figure 2.

Figure 3.

Figure 3A

SPIN STABILIZED

F

E

D

C

B

A