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A DECISION-MAKING PROCESS FOR SELECTION OF A
LOW-KILOWATT SPACE NUCLEAR POWER SYSTEM FOR DEVELOPMENT

by

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PROBLEM Low kilowatt range, electric power system required for space use.

QUESTION What type of system should be developed?

DECISION 1 Thermoelectric or Dynamic?

This decision will be dominated by the cost of fuel and by the manner in which this cost is to be recovered.

Present cost estimate of heat source costs (fuel and fabrication) is \$1M per 250 W(th). Cost differential for the heat source only, T/E to dynamic, per 1 kW(e) would be:

T/E average η = 7.5%	kw(th) = 13.3	\$ = \$53.3M
dynamic average η = 20.0%	kw(th) = 5.0	\$ = \$20.0M

This would probably be decisive in favor of dynamic systems if the user had to pay these costs.

However, there is some suggestion that for military applications, isotope fuel might be costed as weapons fuel. This raises the fuel cost to a different decision level, namely, which does the U.S. need more: Pu^{238} or Pu^{239} ?

If the isotope fuel can be costed in this manner, the question of T/E or dynamics becomes a meaningful question, and T/E systems have several advantages.

T/E ADVANTAGES:

1. Reliability

- a. MHW is fully developed and flight proven.
- b. GPHS-RTG largely developed, soon to be flown.
- c. MITG is a design refinement of GPHS-RTG with improved performance at modest risk.
- d. All systems are highly redundant.

2. Stability

Static system introduces no moments and no vibration into spacecraft.

3. Survivability

T/E systems are inherently hard against all recognized threats.

4. Costs

Absent the fuel cost, the development costs of MITG would be much less than any dynamic system. (Recurring unit costs may favor dynamic systems.)

5. Specific Power

With current systems, the weight advantage would lie with T/E up to 2 or 3 kW(e).

DYNAMIC ADVANTAGES:

1. Geometry

They will probably integrate with the spacecraft better, particularly at the larger outputs.

2. Heat Rejection.

Their higher efficiency reduces the heat rejection load at any output, making them easier to handle throughout a mission.

3. Growth

Dynamic systems have more growth potential.

CONCLUSION:

First big decision point is to determine the chance of external financing of the fuel. If favorable, RTG's are quite attractive, at least at one or two kilowatts. If unfavorable, dynamic systems are strongly favored. The next decision point is the selection of the most promising dynamic system.

DECISION 2

We can consider four types of dynamic systems and compare them first on the basis of fuel costs per 1 kW(e):

Rankine, Organic	$\eta = 17\%$	kw(th) = 5.9	\$ = 23.5M
Rankine, Potassium	$\eta = 19\%$	kw(th) = 5.25	\$ = 21.0M
Brayton, Helium	$\eta = 24\%$	kw(th) = 4.15	\$ = 16.7M
Stirling, Helium	$\eta = 30\%$	kw(th) = 3.3	\$ = 13.3M

We next consider the operating characteristics of these systems to determine which would be most attractive for potential missions, assuming that all are developable. This decision requires an understanding of mission requirements.

Weight: Probable order of ranking;
Rankine, potassium lightest
Rankine, organic
Stirling, helium
Brayton, helium heaviest

Radiator:	<u>Temperature</u>	<u>Size</u>
Rankine, potassium	highest	smallest
Stirling		
Rankine, organic		
Brayton		

Stability

Brayton - highest: rotating unit, fluid flow only
Rankine (both) intermediate: rotating unit plus potential mass
slugging and movement due to vapor condensation

Stability (Cont'd)

Stirling: worst: reciprocating masses plus fluid flow,
possibly rotating mass.

Survivability:

This is a complex problem that is of great significance to military systems. Much study is needed. The most obvious form of damage is thermal and mechanical shock to the radiators. All systems are likely to suffer degradation in performance due to surface changes. Rankine systems are more prone to irrecoverable shut-down due to severe thermal transients.

Having considered the order of system attractiveness for potential missions of interest, it remains to consider the relative development risks, costs, and time spans for the several systems. The systems are discussed in order of increasing development difficulty.

1. Brayton, helium: This system is closest to a well established and reliable technology, namely gas turbines and compressors. Initial reliability can be enhanced at the cost of some performance by avoiding exotic, unfamiliar materials and excessive temperatures. The first basic feasibility question is really how long can a conservative system operate unattended? The soundest approach would be to establish multiyear unattended operating capability first, then upgrade performance by decreasing conservatism. Since this would be a time-consuming procedure, a practical compromise is to develop components simultaneously at several levels of conservatism, selecting the most promising system available in time to meet a real mission requirement. Major feasibility items are bearing design, materials of construction, and operating temperatures.

2. Rankine, organic: The technology of small organic Rankine systems is less well developed than Brayton systems. The lower temperatures of the Rankine systems is a big factor in their favor, but two major feasibility items must be recognized: long-term stability of the working fluid, and operating of a condensing system in zero gravity. The same general approach of starting with a conservative system and upgrading it based upon success is again recommended. However, zero gravity operation cannot be proven short of a flight system.
3. Rankine, potassium: This system promises higher performance than the organic Rankine, but the basic technology is less well developed. The instability of organic fluids is eliminated but the potential for reactions between the liquid metal and its complex containment system is substituted and is probably at least as troublesome. In general, it is more expensive and difficult to work with liquid metal systems than with less reactive systems.
4. Stirling: This system must be considered the most developmental by a large factor. First, agreement does not exist on which Stirling system has the most promise, since several different concepts are, or have been, under development. After making a system concept selection, it remains to refine component designs and develop a working system. Finally, given a working system, a major effort remains to establish long life reliability, since no functioning commercial technology exists. The magnitude of this development effort would seem to rule out Stirling systems unless their performance characteristics are mandatory. The system would be more attractive as a back-up effort for future use, if funding were available.

SUMMARY

The following decision-making process is recommended:

1. Review fuel costing ground rules. If fuel can be provided GFE, thermoelectric systems become quite attractive for near-term use in the low-kilowatt range. If costs must be borne by the user, a dynamic system is mandatory
2. If a dynamic system is required, the operating characteristics of the several possible systems should be compared with the best current definition of mission requirements. This will put the systems into order of user desirability.
3. Expand the analysis of the required development efforts presented above; evaluate the time and funding available; initiate program on that system that offers the best performance at the lowest risk for the time and dollars available.