Technical Comments

Comment on "Large Space Station Power System"

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THE article by J. E. Boretz[4] develops the type of comparisons needed by developers and potential users of large space station power systems. It was a particularly interesting article because he meticulously listed his selection rationale and pertinent factors. Consequently, because of the value of such data I would like to up-date the assumptions regarding radioisotopes and show the effects on the results.

It is true that β emitters are usually easier to produce than α emitters and can be produced in much larger quantities at far less cost. The statement "β shielding requirements are much higher [than for α emitters, thus] increasing system weight and greatly complicating handling, safety in abort, and recovery problems" would be true only if one tried to fit a β emitter like Co-60 into a heat source concept developed for an α emitter such as Pu-238.

It has been shown[1] that Co-60 and Pu-238 heat source weights are comparable in the multikilowatt power range if

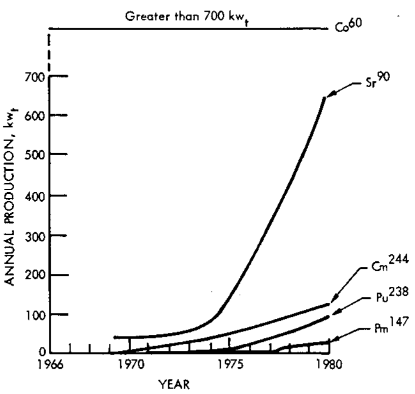

Fig. 1 Potential production of isotopes based upon projected installed civilian power.

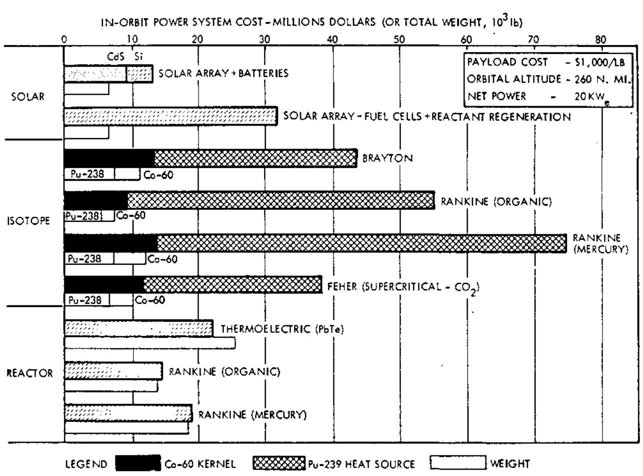

Fig. 2 Candidate power systems—weight and cost comparisons.

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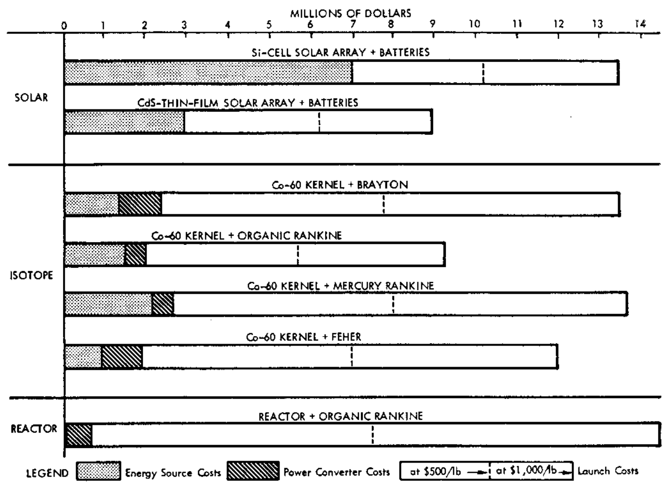

Fig. 3 Major items of cost for in-orbit power.

the Aerojet Kernel is used for the Co-60 source. The initial space safety study of the Co-60 Kernel[2] sponsored by the AEC-Space Nuclear Systems indicated that this source would survive all hazards of ground handling, flight, and disposal. In addition, the relatively low cost and shorter half-life of Co-60 rule out the necessity for recovery after use, thereby significantly reducing application costs and system complexities. The net result is that the Co-60 Kernel is the strongest radioisotope candidate for large electric power systems.

The relationship of Co-60 availability to other isotopes, and of Co-60 Kernel power systems to other sources is shown in the reprints of Figs. 7, 12, and 13 from Boretz' paper relabelled here Figs. 1, 2, and 3, respectively. The only change made in each case was the addition of the Co-60 fuel and kernel system. Costs and weight for the power system include the Co-60 fuel with a decay allowance priced at reported SRL costs,[3] and the kernel heat source with it heat management and re-entry systems.

References

[1] Ruehle, W. and Forrest, D. L., "The Compact Co-60 Kernel for Space Power," paper 699036, Sept. 22–26, 1969, Intersociety Energy Conversion Engineering Conference.

[2] "Design Definition and Safety Evaluation Study of a Compact Co-60 Heat Source in Space," Final Report, AGN-8341, Sept. 1969.

[3] "Savannah River Laboratory Isotopic Power and Heat Sources," Quarterly Progress Report, DP-1129-1, July–Sept. 1967 Atomic Energy Commission.

[4] Boretz, J. E., "Large Space Station Power Systems," *Journal of Spacecraft and Rockets*, Vol. 6, No. 8, Aug. 1969, pp. 929–936.

Reply by Author to W. Ruehle

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THE Technical Comment provided by W. Ruehle to Ref. 1 pertained to the desirability of considering the use of the β emitter isotope, Co-60, rather than the recommended α emit-

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ter isotope, Pu-238, as a heat source for large electric power systems.

In general, when selecting an isotope heat source for a particular space application both quantitative and qualitative factors must be taken into consideration. The characteristics listed in Table 3 of Ref. 1 (with the exception of cost) fall in the quantitative category and hence are not very controversial. Other factors such as cost, availability, shielding and encapsulation, handling, safety in abort, and recovery are not as straightforward. In many instances these latter factors are dominated by AEC policy and safety considerations.

W. Ruehle[2] refers to Refs. 3–5 to justify the merits of the Aerojet Co-60 Kernel heat source. In order to reply to his comments, it was necessary to review these references. The following summary statements and comments are a result of the review.

1) The Co-60 Kernel Concept[3] consists of encapsulating 30 kw of Co-60 isotope fuel in metallic form in 6 capsules of 5 kw each. The capsule material is a tungsten-25% rhenium alloy (*W* 25 *Re*). The six fuel capsules are contained within a nearly spherical tungsten radiation shield which in turn is sealed within an oxidation protection shell of Hastelloy C. The Kernel heat source is 18.7 in. in diameter and weighs 2255 lb when sized for a dose rate of 100 mr/hr at one meter. For the safety study,[4] the Kernel and a thermal management system were assumed to be contained in a blunted cone reentry shell.

2) The author concurs that from a weight standpoint the Co-60 Kernel and Pu 238 heat source weights are comparable at the beginning of the mission. However, the shorter half life of the Co-60 isotope (5.3 yr) over a nominal 2-yr mission results in a power decrease of approximately 25%. This must be compensated for by additional beginning-of-life isotope inventory and excess-power dissipation controls and thermal matching. This leads to increased system complexity and weight. If the isotope inventory is not increased, a lower cycle conversion efficiency at EOL could result. For example, the Brayton cycle at NASA Langley Research Center has nominally been designed for a maximum working fluid temperature of 1640°F at the turbine inlet. Any heat source power degradation and the resultant change in working fluid temperature would have to be taken into account in the system design.

3) The safety study,[4] was a preliminary effort whose scope did not permit evaluation of all potentially hazardous environments. It does not adequately justify the statement,[2] "The initial space safety study of the Co-60 Kernel[4] sponsored by the AEC-Space Nuclear Systems Division indicated that this source would survive all hazards of ground handling, flight, and disposal." Not only did the investigators fail to evaluate several potentially severe hazards, but in those cases investigated left serious doubts as to the integrity of the Kernel after exposure to the hazardous environments.

4) Recovery after use appears to be the current Atomic Energy Commission Safety Policy. Hence, despite the potential lower cost and shorter half-life characteristics of Co-60, recovery after use cannot be ruled out. Costs and system complexities associated with this requirement, therefore, still exist for the Co-60 Kernel.

5) There do not appear to be any directly applicable long-term data on the compatibility of the Co-60 fuel with the proposed *W-Re* fuel liner. Their material selection was based on "preliminary studies" and on the use of this material with other radioisotopes.

6) There is a potential problem in that molten Co-60 may not be compatible with *W-Re*. Even in the event of a liquid booster launch pad abort residual fire, the fuel will probably melt.[4] As in item 5, there are no compatibility data for molten Co-60 in contact with *W-Re*. Although higher melting point Co-60 fuel forms are under development, a fuel form other than metal will have decreased power density, thus increasing system weight for a fixed external radiation field.

7) For the liquid booster launch pad abort residual fire, some melting of the Hastelloy C shell was found analytically.[4] In a solid booster launch pad abort, melting of the shell and extensive erosion of the *W* radiation shield is likely, due to the much higher temperatures and longer burning times associated with the solid propellant fire and to the low melting temperature alloys formed by the refractory alloy radiation shield and the propellant combustion products. Additionally, the radiation shield could undergo stress failure in a solid-propellant fire, thus releasing the thin-walled fuel capsules into the fire, since yielding of the shield was found for the lower temperature liquid fire.

8) The assembly process for the Co-60 Kernel involves some complicated, untried procedures.[3] Since it is stated that surface diffusion represents a faster migration than grain-boundary or volume diffusion through the shield, to provide an effective cobalt diffusion barrier this shield must be one continuous block with no discontinuities that permit rapid surface diffusion. Shield strength requires recrystallization and swaging, but machines are available with only sufficient capacity to fabricate small body sections. Therefore, these small body sections must somehow be bonded by pressure and heat to form a one-piece shield. After fueling, a plug is inserted which must be designed with sufficient plug-to-body contact to assure final bonding after some time at the elevated temperatures created by the fuel heat.

9) At the temperatures required of the Co-60 Kernel in a Brayton cycle application, there will be appreciable chromium evaporation from the Hastelloy C shell at its operating temperature (approximately 1650°F) and loss of shell strength. This phenomenon could have significant influence on the integrity of the Kernel during post-mission reentry, impact, and post impact. It is suggested that the Kernel be encased in a chamber filled with an inert gas or the shell can be made of an alternate, as yet undeveloped, material.

10) The re-entry analyses conducted[4] were insufficient to assure intact reentry. The Kernel was assumed to be within the blunted cone reentry body, and only two re-entry cases were examined. It was assumed that the re-entry body was oriented at all times with the conical surface receiving stagnation heating. Further, heat transfer from the stagnation point on the re-entry body to the Kernel was neglected, and only wake heating was investigated.

11) There is no conclusive evidence that the radiation shield will be integral after impact. Some very basic analyses were presented in the study,[4] but TRW Systems and others have found that impact testing is the only acceptable method of predicting impact effects.

In view of the foregoing, at its current state of development, it appears to be premature for W. Ruehle to state "that the Co-60 Kernel is the strongest radioisotope candidate for large electric power systems."

References

[1] Boretz, J. E., "Large Space Station Power Systems," *Journa of Spacecraft and Rockets*, Vol. 6, No. 8, Aug. 1969, pp. 929–936.

[2] Ruehle, W., "Comment on 'Large Space Station Power Systems,'" *Journal of Spacecraft and Rockets*, Vol. 7, No. 5, May 1970, p. 639.

[3] Ruehle, W. and Forrest, D. L., "The Compact Co-60 Kernal for Space Power," paper 699036, presented at the 4th IECEC at Washington, D.C., September 1969.

[4] "Design Definition and Safety Evaluation Study of a Compact Co-60 Heat Source in Space," Final Report, AGN 8341, AECAT(29-2)-2740, Sept. 1969, Aerojet-General Nucleonics

[5] "Savannah River Laboratory Isotopic Power and Heat Sources," Quarterly Progress Report, DP-1129-1 AECAT(07-2)-1, July-Sept. 1967.