GAS-COOLED REACTOR POWER SYSTEMS FOR SPACE

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Background

Large amounts of electric power are required for some of the systems envisioned in support of our strategic defense. Since various applications are being considered, and an overall power architecture study has not been completed, the required power levels and corresponding operating times for specific systems are not known. In this paper the characteristics of six designs for power levels of 2, 10, and 20 MWe for operating times of 1 and 7 y are described. The operating conditions for these arbitrary designs were chosen to minimize system specific mass.

The designs are based on recent work which benefits from earlier analyses of nuclear space power systems conducted at our Laboratory. Both gas- and liquid-cooled reactors had been considered. Pitts and Walter (1970) reported on the results of a detailed study of a 10-MWe lithium-cooled reactor in a potassium Rankine system. Unpublished results (1966) of a computer analysis provide details of an argon-cooled reactor in an argon Brayton system. The gas-cooled reactor design was based on extensive development work on the 500-MWth reactor for the nuclear ramjet (Pluto) as described by Walter (1964). The designs discussed here draw heavily on the Pluto project experience, which culminated in a successful full-power ground test as reported by Reynolds (1964). At higher power levels gas-cooled reactors coupled with Brayton systems with advanced radiator designs become attractive.

System Performance

The systems that were evaluated in order to arrive at the minimum specific mass designs are arranged in a conical configuration. Four cases were investigated. Cases 1 and 2 are indirect cycles with and without a regenerator in the power conversion loop, respectively. Cases 3 and 4 are direct cycles with and without a regenerator, respectively. In all cases heat is rejected from the power conversion loop by direct contact of the working gas in a liquid-droplet heat exchanger as described by Bruckner (1985). Ultimate heat rejection to space is accomplished by an as yet broadly defined radiator. Two types are candidates: the electrostatically charged liquid-droplet radiator and the spray-on rotating or static membrane radiator. The spray-on static-membrane radiator was modeled to obtain the system performance/mass results presented here.

System performance is determined using conventional equations and correlations. Each component in the system is modeled to determine its mass as a function of relevant system parameters such as temperature, pressure, and working fluid. The many resulting equations are solved simultaneously using a method developed by Blackketter (1986). The equation set is solved for various combinations of cycle temperature ratio and turbine
pressure ratio according to a systematic procedure which seeks the minimum system specific mass. The same equation solver can be used near the "optimum" to evaluate the sensitivity of all the parameters, known or unknown, in the equations.

An allowable material strength for the higher temperature components as a function of temperature was prescribed for a super alloy and a high-creep-strength refractory alloy. Successful development of the refractory alloy is presumed. The radiator designs considered are assumed to be inherently invulnerable to meteoroid damage, and it is assumed that all piping and pressure vessel thicknesses are established by structural rather than meteoroid considerations.

The system specific mass and other salient characteristics for the four thermodynamic configurations at the six design points are presented. (Note: Not available at the time this summary was prepared.)

**Reactor Characteristics**

The reactor configuration is shown in Fig. 1. It is a prismatic ceramic core reactor composed of several thousand "pencil shaped" tubes made from a homogeneous mixture of moderator and fuel. The tubes are held together by radial compression forces exerted by girdle springs on the cylindrical surface of the core. A layer of zirconia insulation between the fueled core and the girdle springs allows the inlet reactor gas to cool the springs and the reactor pressure vessel before flowing through the core. Spring force requirements are minimal since maneuver loads are very low, and gas pressure gradients are favorable. This allows the springs and pressure vessel to be made from nonrefractory metals. The modest pressure drop through the core is supported at the outlet end by a ceramic dome, designed to experience only compressive stresses. Inlet and outlet reflectors are made from the same moderating material as in the core.

Fig. 1. Reactor configuration assumed in the system study.
Several core material choices are possible. Boron carbide with uranium boride (boron-11 isotope), beryllium oxide with uranium dioxide, and carbon with uranium dicarbide were evaluated. These materials all provide a thermal or epithermal neutron spectrum in the sizes considered. Based on their volatilities, these material systems are estimated to be useful at temperatures up to about 2000, 1950, and 2200 K, respectively. Higher temperatures could be achieved with appropriate coatings. Only a negligible difference in system mass results for identical geometry reactors for different material systems. Study and experimental work is required to quantify irradiation effects at high burnup, and fission product retention for all three material choices.

The anticipated structural, chemical, and thermal properties of the boron system make this a leading candidate, particularly for high burnup missions where a burnable poison (boron-10) would be desirable. Sufficiently pure boron-11 can be obtained at a reasonable cost with the desired amount of boron-10 for reactivity control over the design operating life. The reactor modeled for the system performance results presented is based on a boron core.

The beryllium oxide system is also an outstanding candidate. This system is highly developed (Pluto project), has good mechanical and physical properties, and results in the lowest critical mass for the same size and porosity reactor. A possible drawback (which needs to be evaluated more fully) is to what extent its toxicity represents a hazard to the public in the event of a launch accident.

As in the case of beryllium oxide, the carbon system is also highly developed (nuclear rocket), has the highest operating temperature capability, and has excellent thermal stress characteristics. Multiple hole fuel elements are more feasible in the carbon system, should that be desirable. The major disadvantage of the carbon system is its relatively high critical mass. Nevertheless, all three material systems result in considerably lower fuel inventories than would be required for fast reactors.

Control of thermal reactors made from these material systems is accomplished by a variable-leakage reflector and internal control rods. The reflector, which has a high reactivity worth despite the return coolant annulus surrounding the core, would be moved axially to effect control. The internal control rods may be made of hafnium (Walter, 1964) or boron carbide. Details of the absorber rods and their actuators are not yet available.

**Conclusions**

Gas-cooled thermal reactors coupled with Brayton cycle power conversion appear to provide reasonable multi megawatt space power systems. An advanced radiator design must be developed which can meet the mass limit assumed in this study. The inherent high temperature capability of the reactors considered removes the reactor as a limiting condition on system performance. The low fuel inventories required, particularly for beryllium oxide reactors and shorter design operating times, make space power systems based on thermal reactors a lesser safeguard risk.

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