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THERMAL AND DYNAMIC ANALYSIS OF THE RING POWER SYSTEM RADIATOR

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Background

The nuclear option for a space-based power system appears most suitable for missions that require long-term, sustained operation at power levels above 100 kW_e. Systems currently available operate at relatively low thermal efficiencies (6 - 10%). [1] Thus, a 100 kW_e system must discharge nearly 2 MW_{th} of waste heat through the comparatively inefficient process of radiative cooling. The impact of the resultant radiator assembly size on overall power system weight is significant, and has led to proposals for radiators with potentially higher efficiencies. Examples include the: (1) Liquid droplet radiator; [2-4] (2) Fabric radiator; [5] (3) Bubble membrane radiator; [6] (4) Rotating film radiator; [7] and (5) Dust radiator. [8,9]

RING System Description

An alternative radiator design has recently been developed by the authors which reduces system vulnerability and the extent of necessary pre-deployment testing. [10] The prototype design is identified by the acronym **RING** (Radiatively-cooled, Inertially-driven Nuclear Generator). As shown in Figure 1, the **RING** power system employs four counter-rotating, hollow, cylindrical, ring-shaped tubes filled with liquid lithium. The rings pass through a cavity heat exchanger, absorb heat, and then re-radiate the absorbed heat to the space environment. Each ring is made of thin-walled, corrugated tubing with external fins. The tubing is segmented to minimize the consequence of coolant loss. The rotating rings also provide gyrostatic precession forces for control of mission platform orientation and stability.

The **RING** power system is basically a two-stage capacity cooler. Capacity coolers for heat rejection in space, such as the moving-belt and disk radiators, were proposed as early as 1960. [11,12] However, to obtain efficient heat transfer and reduce the size of the primary / secondary interface, those earlier designs used conduction, rather than radiation, to transfer the waste heat from the primary source to the heat sink. The **RING** design, on the other hand, relies totally on radiative heat transfer for waste heat removal. Reasonable radiator size is maintained by two key design features: (1) The available protection in an enclosed cavity heat exchanger allows the use of exotic materials with higher emissivities and thermal conductivities; and (2) Natural convective heat transfer in the lithium-filled pipe is induced by the rotational motion of the ring, and enhanced by a radial temperature gradient in the tube (caused by directional heating in the cavity).

Thermal and Dynamic Performance

The computational analysis to model the dynamic and thermal hydraulic performance of the **RING** power system requires a set of five computer codes. As shown in Figure 2 these codes handle data (RINGDATG), analyze the system thermal hydraulic performance (RINGSYS), determine the natural convective heat transfer in the individual ring segments (CELESTE), establish the dynamic performance and limits for the system (RINGDYN), and graphically present the results (PLOTDAT). Preliminary results for a 5 MW_{th} heat rejection reference case are shown in Table 1.

Table 1 Design Description and Performance (5 MWth)

Dimensions		**Materials**		
Ring Diameter	10 m	Fluid -	Lithium (93% ^{7}Li)	
Fin (tip-tip)	30 cm	Pipe & Fin -	Nb-1Zr	
Pipe (ID)	12.25 cm	Wear Surface -	Cemented Carbide	
Cavity Heat Transfer Area	12.5 m^2	Coating -	Niobium Substrate Exterior: Ti and Zr Oxide Coating	
Segment Length	1.5 m			
Thicknesses		**Design Comparison**		
Fin	.55 cm	SP-100	1200	kg [13]
Pipe	.55 cm	Liquid Droplet	500	kg [14]
Coating	.075 cm	RING	2100	kg

Cavity	Temperature	1700 K	Effective Emissivity	.95
Ring	Maximum Temperature	1000 K	Minimum Temperature	800 K
	Effective Emissivity	.85	Velocity	5 m/sec
	Radial Force:	7500 N	Stored Energy:	.005 kw-hr

Recent investigations have focused on enhancing the ring's stability and internal natural convective heat transfer. These studies included: (1) Evaluation of the effect of partial lithium fill on viscous dampning of the ring; and (2) Examination of how preferentially heating one side of the ring as it passes through the cavity affects the amount of induced convective heat transfer.

Conclusions

As shown in Table 2, the **RING** concept has inherent system advantages and disadvantages. The 5 MW_{th} reference design is approximately 75 % heavier than a comparable SP-100 system, and requires a maximum fuel surface temperature 200 to 300 K above the current SP-100 materials limit. In addition, system performance is extremely sensitive to the amount of natural convective flow that can be induced in the rotating ring segments. Despite these constraints, the concept appears to have potential as an emergency backup cooling system, or for waste heat removal from an advanced, high temperature reactor (ex. fluidized bed, gaseous core, or liquid core). A preliminary analysis of the **RING** radiator system indicates that the design is an attractive option, especially where the essential design criteria are reliability, safety, and repairability.

Table 2 Design Summary

Advantages	Disadvantages
Lower Loss-of-Coolant Accident Vulnerability	Higher Weight and Reduced System Efficiency
	Potential for Uncontrolled Precession Forces
Ability to Use Special, Protected Materials in Cavity Heat Exchanger	Thermal / Radial Expansion Joints, Motive System and High-Temperature Contact Surfaces
Ease of Ground-Phase Testing, Assembly, Startup and Component Repair	Thermal Impact on Mission Platform and No Biological Shielding by Radiator
Limited Collateral Use for Platform Precession Control / Energy Storage	Higher Required Reactor Fuel Temperatures

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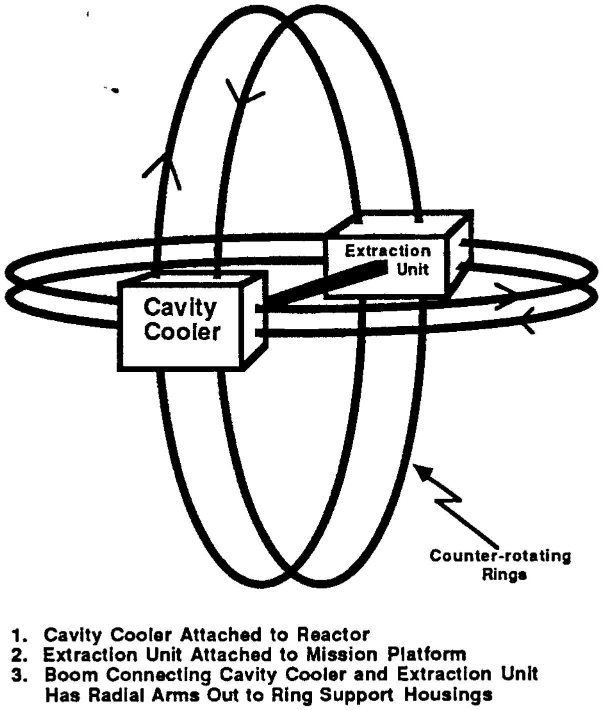

Figure 1 - Schematic of RING System

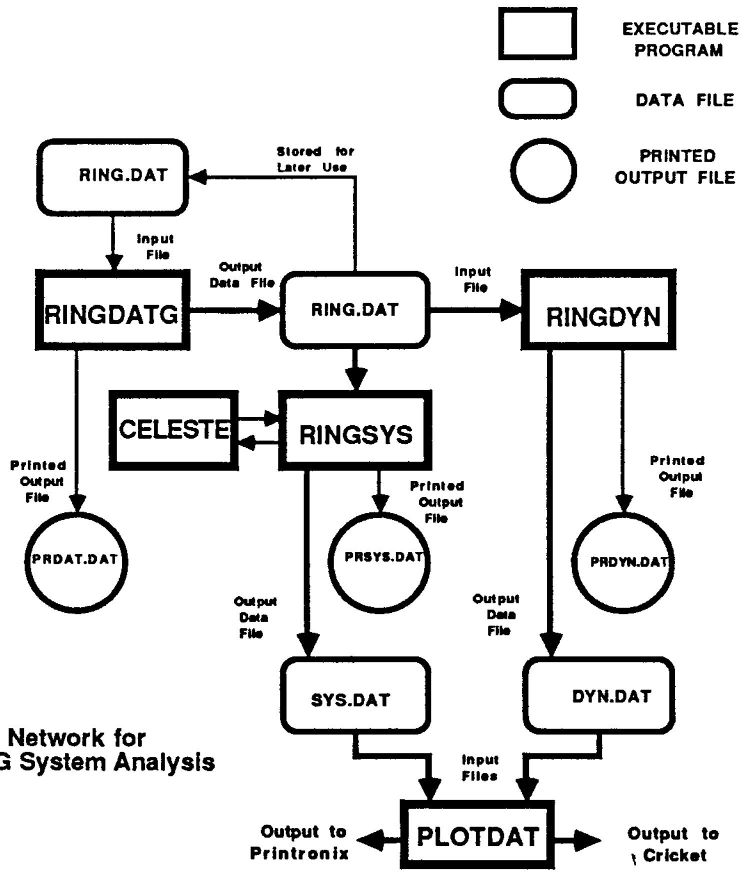

Figure 2 - Code Network for RING System Analysis