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SPLIT-CORE HEAT-PIPE REACTORS FOR OUT-OF-PILE THERMIONIC POWER SYSTEMS

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ABSTRACT

The concept of splitting a heat-pipe reactor for out-of-core thermionics into two identical halves and using the resulting center gap for reactivity control is described. Short ^{7}Li-W reactor heat pipes penetrate the axial reflectors and form a heat exchanger with long heat pipes which wind through the shield to the thermionic diodes. With one reactor half anchored to the shield, the other is attached to a long arm with a pivot behind the shield and swings through a small arc for reactivity control. A safety shim prevents large reactivity inputs, and a fueled control arm drive shaft acts as a power stabilizer. Reactors fueled with ^{235}UC and with ^{233}UC have been studied.

I. INTRODUCTION

A. Need (Fig. 1)

Sometime in the future man will be putting large systems into space, including those for his own habitation. These will require larger energy sources than batteries and solar arrays can conveniently provide. These sources will need to have high reliability for a long period of time as well as be compact and have a low weight. Lewis Research Center is currently conducting technology studies on small reactors which have the capability to handle the requirements for such missions. The split-core heat-pipe reactor is one of these concepts.

B. Difference

1. <u>Pumped-Loop vs Heat-Pipe</u> (Fig. 2)

The use of heat pipes for heat removal in place of a pumped coolant loop allows major structural differences in the reactor design. The coolant is sealed in a number of heat pipes; therefore, the need for a pressure vessel is eliminated. At the same time the need for coolant loop machinery, e.g., pumps and pressurizers, rotating seals and bearings, is eliminated.

Since each coolant channel essentially has its own pressure vessel in the form of the heat-pipe wall and each heat pipe operates independent of any other, major accidents due to loss of coolant or loss of flow are precluded.

When heat is applied to one end of a heat pipe, startup is automatic, even from a frozen state, and so is its response to changes in the heat load within its operating range. Hence, coolant preheaters and after heat removal subsystems are not needed.

2. <u>In-Core vs Out-of-Core Thermionics</u> (Fig. 3)

Although this reactor could be used with other conversion techniques it was conceptually designed for use with an out-of-core thermionic conversion system. Moving the thermionic diodes out of the core results in a higher fuel density in the core; this decreases the reactor size and shield weight. In addition, higher heat fluxes (250-300 watts/cm^2) can be taken by heat pipes than by diodes (80-100 watts/cm^2) so that the core can have a higher power density. Outside the harsh reactor environment the diodes are open to more freedom of design; fuel swelling damage to collector-emitter spacing and radiation damage to electrical insulators are eliminated, thereby increasing diode reliability. Diode efficiency is also increased - by smaller diode spacings, by having room for larger electrical leads, by isothermal operation, and by absence of fission products to degrade diode performance.

(Fig. 4). In designing this reactor the goals have been simplicity and redundancy. Keeping simplicity in mind we gain by obtaining a lower reactor weight and volume, a reduction in malfunction possibilities (fewer parts to fail), and a reduction in system development time and costs. Keeping redundancy in mind we gain by minimizing malfunction propagation and in the ability to operate in spite of local failures. We then design the components for a long life and find that the criteria (Fig. 1) for auxiliary space power have been fulfilled.

II. REACTOR DESCRIPTION

A. Fuel Pieces and Reactor Heat Pipes (Fig. 5)

The basic building blocks for the core are the reactor heat pipe module and the fuel piece. The cylindrical form in the evaporator section of the heat pipe extends through the reflector block and transforms to a pipe with a rectangular cross section. The reflector blocks join together to form an axial reflector slab with heat pipes penetrating in a square grid. The fuel pieces slip in between the heat pipes, and as the temperature is raised, they expand against the pipes for good thermal contact. The fuel is formed from either fully enriched $U^{233}C$ or $U^{235}C$ cermet with 4 percent volume of tungsten to improve wall bonding and to gain chemical equilibrium in the U-C-W system, and with 20 percent porosity for fuel swelling accommodation. The large central void is included to give the core longer life by providing growth space when the porosity alone can no longer absorb more fission products.

The reactor heat pipes have tungsten walls and wicks and contain a small amount of lithium in liquid and vapor at temperatures around 1800° K when in full operation.

B. Overall Reactor (Fig. 6)

To complete the basic core half a radial reflector with thermal insulation and a center plate to cover the core are added. Two identical core halves together make one split-core heat-pipe reactor. Long heat pipes interlace with the reactor heat pipes in the heat exchangers located adjacent to the axial reflector to form the energy link with the rest of the thermionic conversion system.

Fuel expansion is allowed into the fission gas plenum between the core and the axial reflectors. The plenums are tapped to allow the gases to escape to traps external to the reactor. The radial reflector serves double duty; besides reflecting neutrons it takes the radial expansion load from the core. The reactor heat pipes smooth temperatures in the axial direction and the heat exchangers smooth them crossways, so the diodes tend to be isothermal.

One of the necessities for a long-life reactor at high temperature appears to be a method for releasing fission products from the fuel elements so that they do not cause excessive swelling. Yet at the same time, it is desirable to contain the fission products so they do not contaminate the surroundings. In a reactor cooled by forced convection the amount of high-temperature plumbing required to do this is considerable. In the heat pipe reactor the only plumbing required is a tap into the fission gas plenum. But it also requires a gas-tight seal over a region which includes the reactor and the condenser ends of the heat pipes, which form a series of slabs butted against the axial reflectors. A form-fitting tantalum shroud over the heat pipes and radial reflector welded to a corrugated disc over the center plate provides the seal.

C. Reactivity Control (Fig. 7)

This reactor is controlled by the relative position of the two core halves. Overall movement of the reactor-heat pipe system is complicated by the attached long heat pipes, which wind through the shield to prevent radiation streaming. To minimize movement of the long pipes and shield angle a swing arm is used to both support one reactor half and provide reactivity control; the other core half, as well as the support arm, are attached to the shield. The movement is small; a ^{235}UC core requires about 3 cm of separation between the cores for a 10-$ reactivity control swing; a ^{233}UC core, about 1 cm.

Going to a swing arm control approach rather than to control rods has several advantages. If rods were used other materials would have to be placed in the reactor. This would make the reactor larger and require more fuel. But an even larger penalty occurs in the weight of the shield required to shade the bigger reactor. The materials used in the control rods would have to be able to move freely in a severe environment; the high temperature will cause problems with chemical reactions, galling, sticking, and the like, some of which may be solved by more complicated rod designs involving canning, lining, and possibly an auxiliary cooling system for the rods. All of these problems are alleviated by using a swing arm for control. For operational safety a reactivity input safety lock is provided to limit the amount of reactivity which can be inserted in a single swing arm movement; a scram mechanism could also be included.

Inherent stabilizing influences are felt from the negative temperature reactivity inefficients due to Doppler effects and to thermal expansion. A valuable negative power reactivity coefficient is a fueled control drive shaft. A (Fig. 8) typical fueled shaft could contain the same fuel as the core and could be insulated with BeO. The fuel produces heat in proportion to the reactor power, causing the shaft to expand or contract according to an increase or decrease in reactor power. Some typical results (Fig. 9) presented in Table I, show that the fueled control drive shaft is a good power stabilizer.

III. REACTOR PHYSICS

Parallel parametric reactor physics calculations have been performed on the ^{233}UC and ^{235}UC fuels using cores with the same cell geometry, i.e., 1.1-cm diameter heat pipes in a square lattice with a 2.3-cm pitch. Effective multiplication factors were found for (Fig. 10) reactors with height-to-diameter ratios equal to 3/4 to 1. In considering heat transfer the former has some advantages. A flatter reactor provides a wider base for the heat exchanger and allows larger long heat pipes; it also lightens the load per individual reactor heat pipe by decreasing the length of fuel serviced per heat pipe.

IV. CONCLUSION

The use of heat pipes to cool a reactor has changed many of the design rules with considerable advantage to portable reactors. The simplicity of this reactor cuts the equipment inventory by eliminating the single large pressure vessel, coolant machinery, multiple control rod machinery and auxiliary subsystems for coolant preheating and for after heat removal, thereby reducing the probability of malfunctioning. Simplicity has also enabled the design of smaller cores to gain reactor and shield weight savings. The redundancy of many heat pipes operating independently precludes major consequences from coolant accidents and insures continued useful operation should local failures occur.

1. HIGH RELIABILITY
2. LONG LIFE
3. COMPACTNESS
4. LOW WEIGHT

Figure 1. - Space auxiliary power criteria.

1. NO PRESSURE VESSEL
2. NO COOLANT MACHINERY
3. AUTOMATIC AFTERHEAT REMOVAL
4. NO COOLANT PREHEATERS

Figure 2. - Advantages of heat pipes over pumps for cooling.

1. HIGHER FUEL DENSITY
2. HIGHER POWER DENSITY
3. INCREASED DIODE RELIABILITY
4. REDUCED POWER TAILORING

Figure 3. - Why out-of-core thermionics?

SIMPLICITY

1. DECREASE WEIGHT AND VOLUME
2. REDUCE MALFUNCTION POSSIBILITIES

REDUNDANCY

1. MINIMIZE MALFUNCTION PROPAGATION
2. OPERATE DESPITE LOCAL FAILURES

Figure 4. - Reactor design goals.

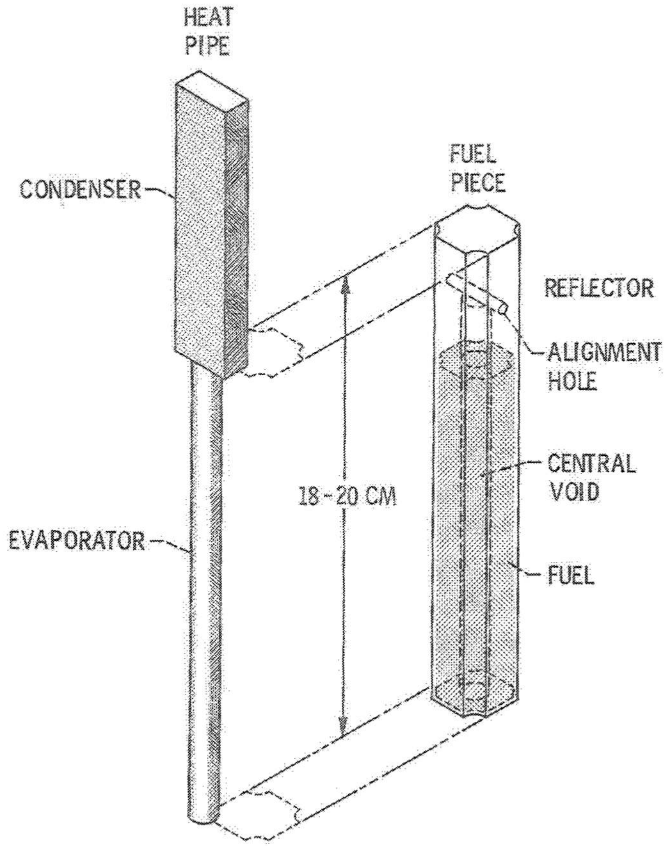

Figure 5. - Core elements.

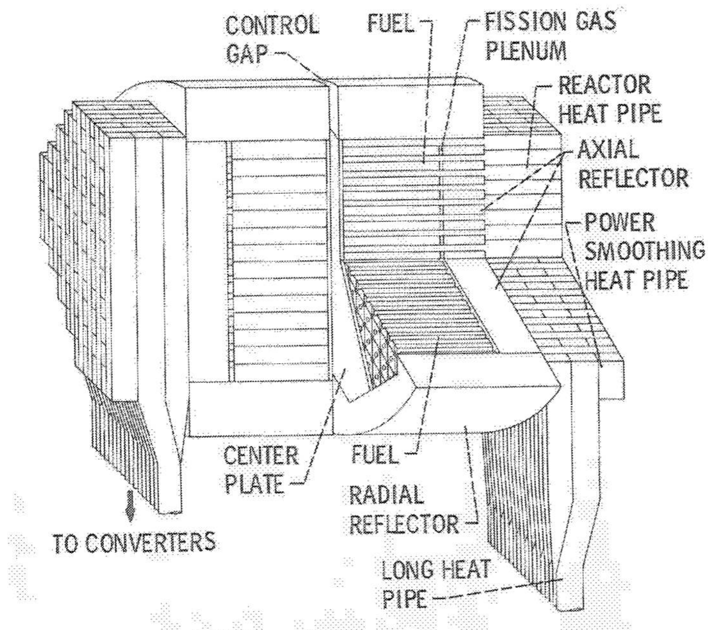

Figure 6. - Split-core heat-pipe reactor.

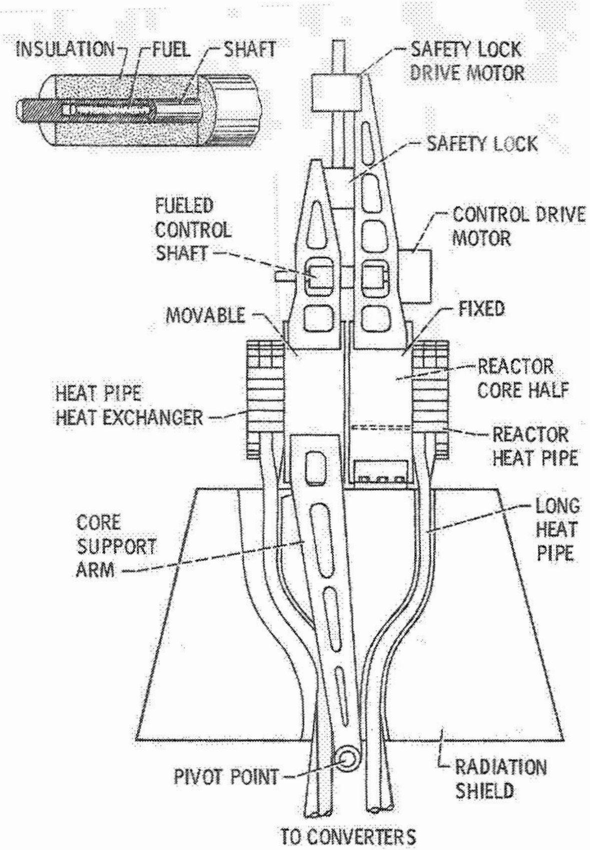

Figure 7. - Split-core heat pipe reactor concept.

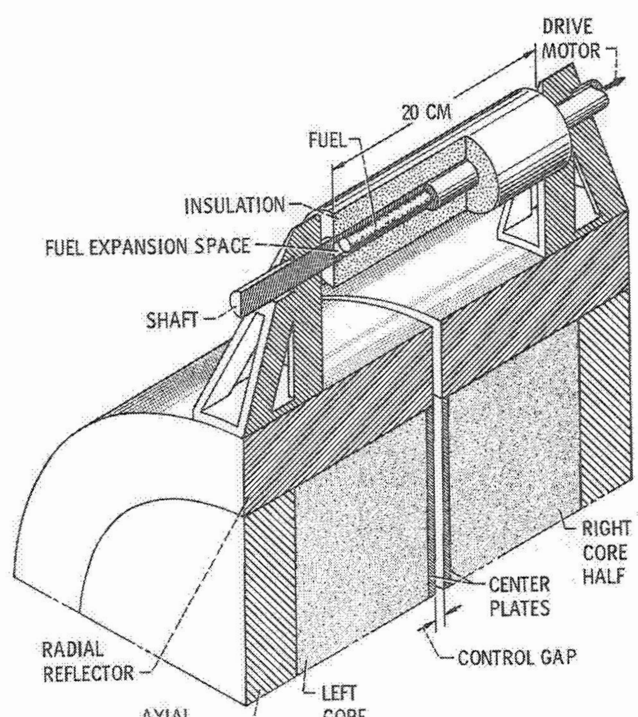

Figure 8. - Fueled control shaft concept.

CONDITIONS: 1 MEGAWATT POWER LEVEL
10 CM LONG SHAFT
10 CM DISTANCE BETWEEN SHAFT AND REFLECTOR
2 CM BeO INSULATION

SHAFT MATERIAL	REACTIVITY COEFFICIENT, -CENTS/MW	
	U^{233}	U^{235}
Mo	51	13
Ta	48	12
W	32	9

Figure 9. - Power reactivity coefficient.

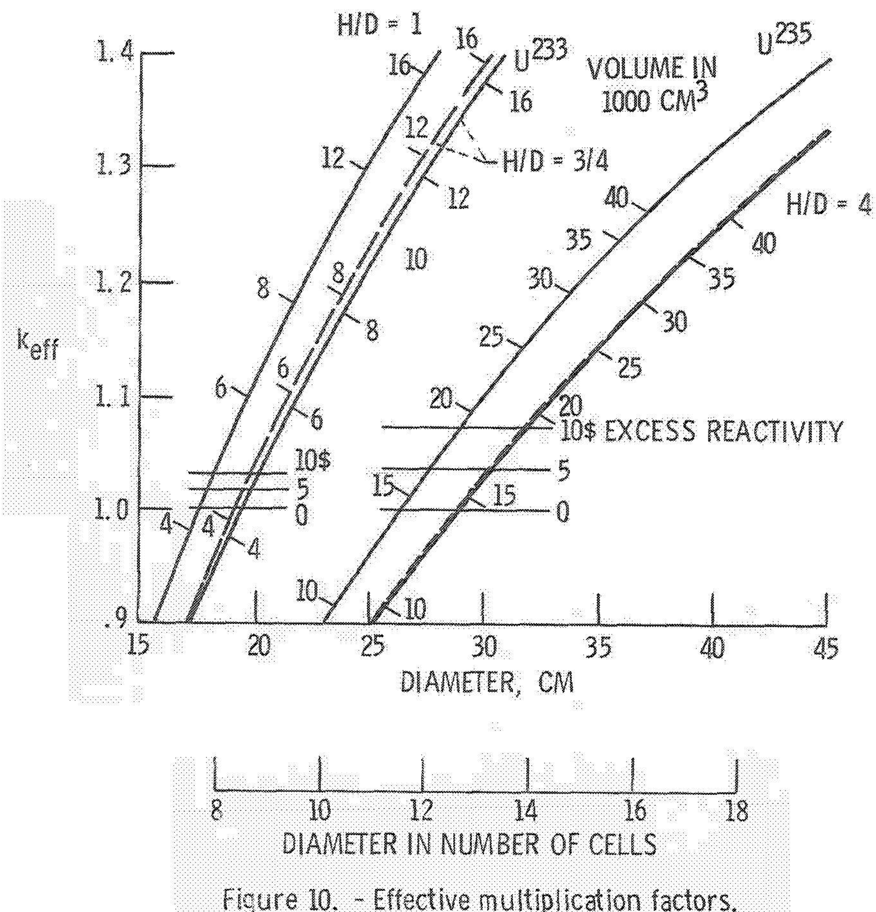

Figure 10. - Effective multiplication factors.