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ULTRA HIGH TEMPERATURE PARTICLE BED REACTOR DESIGN

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ABSTRACT

This study is a computer analysis of a conceptual nuclear reactor.

The purpose of this work is to design a direct nuclear propulsion engine which could be used for a mission to Mars.

The main features of this reactor design are high values for I_{sp} and, secondly, very efficient cooling. This particle bed reactor consists of 37 cylindrical fuel elements embedded in a cylinder of beryllium which acts as a moderator and reflector.

The fuel consists of a packed bed of spherical fissionable fuel particles. Gaseous H_2 passes over the fuel bed, removes the heat and is exhausted out of the rocket.

The design was found to be neutronically critical and to have tolerable heating rates. Therefore, this Particle Bed Reactor Design is suitable as a propulsion unit for this mission.

I. PURPOSE

It is desired to design a direct nuclear propulsion engine which could be used for a mission to Mars.

II. MAIN FEATURES

Two characteristics of the design are high values of I_{sp} and, secondly, efficient cooling. These traits result from the use of a particle bed reactor.

A. The Specific Impulse

$I_{sp} \propto V_{exh}$, where V_{exh} is the rocket exhaust velocity. To increase the I_{sp}:

1. Increase the exhaust temperature, thereby increasing V_{exh}, and/or

2. Operate the reactor at low pressure, allowing the H_2 to dissociate into H_1, reducing the mass of the exhaust particles, causing their velocity to increase. Operation of this design at high temperature and low pressure result in a large value of I_{sp} (see Design Parameters).

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B. Cooling

In the Particle Bed Reactor, the spherical fuel particles have a high surface to volume ratio resulting in very efficient cooling.

III. DESCRIPTION

A. Reactor Core

The Particle Bed Reactor (Figure 1) consists of 37 fuel elements imbedded in a cylinder of solid beryllium, which acts as a moderator and reflector. The fuel elements are cylinders which are distributed in a hexagonal array.

B. Fuel Elements

Each fuel element (Figure 2) consists of four co-axial cylindrical shells. From the largest radius to the smallest, they are:

1. Inlet Plenum
2. Cold Frit
3. Fuel Bed
4. Hot Frit

The frits are porous cylindrical walls which hold the fuel bed.

C. Fuel

The fuel consists of a packed bed of spherical fuel particles (Figure 3). Each particle consists of four spherically symmetric regions. From the smallest radius to the largest, they are:

1. UC_2/ZrC Fuel Kernel
2. Porous Graphite
3. Pyrolytic Graphite
4. ZrC Coating, which does not react with H_2.

Heat is generated by fission and the system is cooled by H_2, which flows radially inward from the inlet plenum, through the porous cold frit, over the packed fuel bed, through the porous hot frit and is exhausted axially out the channel formed by the hot frit.

D. **Design Parameters**

Power (MW)	1000.
Fuel Bed Power Density (MW/l)	5.
Outlet Frit Mach Number Limit	.3
Outlet Temperature (K)	2000-4000
Outlet Pressure (ATM)	5.
Estimated I_{SP}(s)	900-1600
Pitch (CM)	19.43
Height (CM)	124.
Core Radius (CM)	68.
Vessel Thickness (CM)	1.
Fuel Bed Mass (Kg)	496.
Moderator Mass (kg)	1767
Miscellaneous [Vessel, etc.] (kg)	700.
Estimated Total Mass (Kg)	3000.

IV. METHOD

Various computer codes were used in the analysis.

A. Neutronics

One set dealt with the neutronics. A Monte Carlo neutron transport code was used to determine the criticality and the heating rates of the system.

B. Thermal Hydraulics and Heat Transfer

A second set dealt with the thermal hydraulics and heat transfer. Conservation of energy, and transfer of heat, from the solid material to the H_2 coolant, were incorporated into a finite element description of the reactor.

V. RESULTS

A. Neutronics

1. The neutronic analysis showed that the proposed reactor design is neutronically critical. K_{eff} is easily changed by varying the size of the fuel kernel (but keeping the particle O.D. constant), thereby changing the fuel loading.

2. Despite the neutron streaming out of the exhaust holes, the reactor is critical.

B. Heat Transfer

1. The structural components and the moderator would absorb about 40 MW of power and would be readily cooled by the H_2 before it enters the fuel bed.

2. Despite the low pressure of the system, high power is produced because of the favorable heat transfer properties of the fuel particles.

VI. CONCLUSION

The Ultra High Temperature Particle Bed Reactor is suitable as a propulsion unit for a mission to Mars.

REACTOR CROSS SECTION

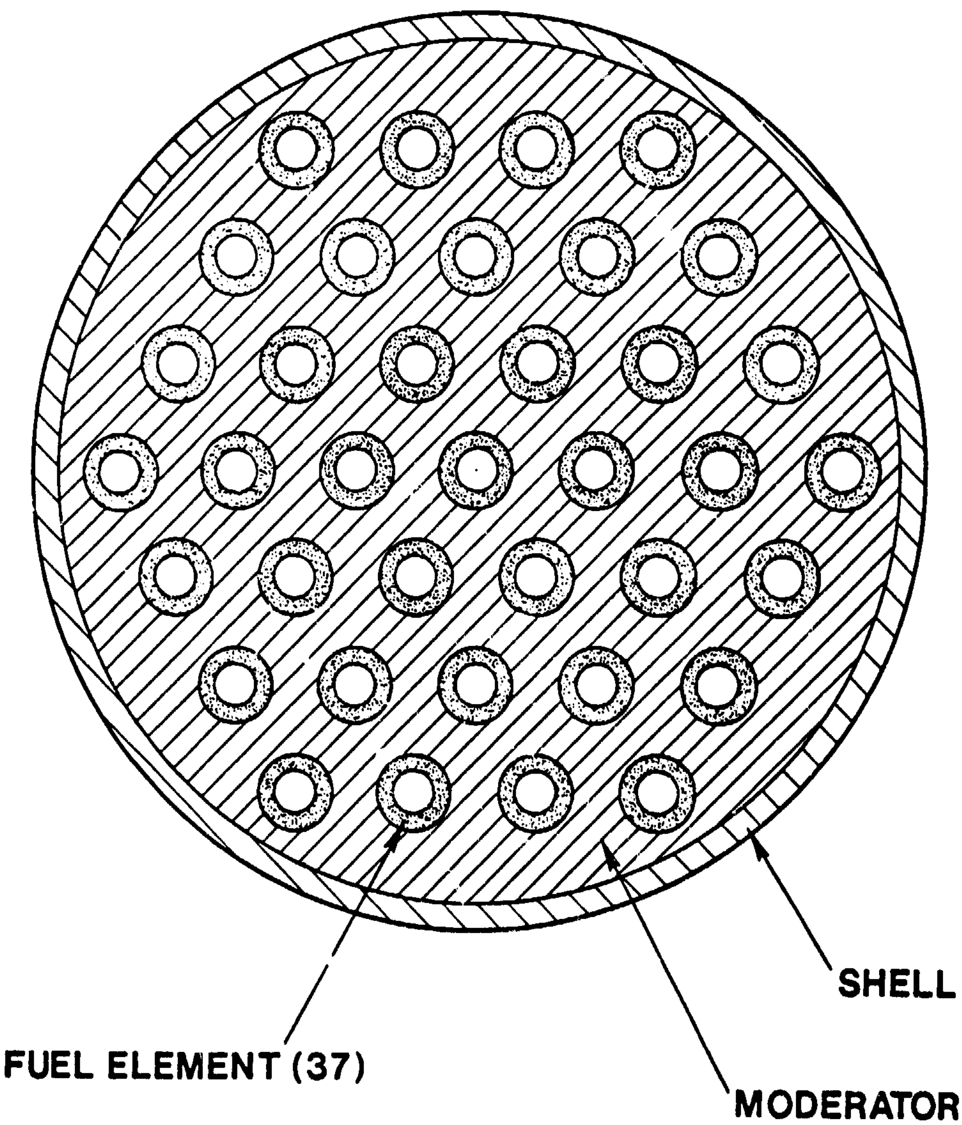

FIGURE 1

UNIT CELL

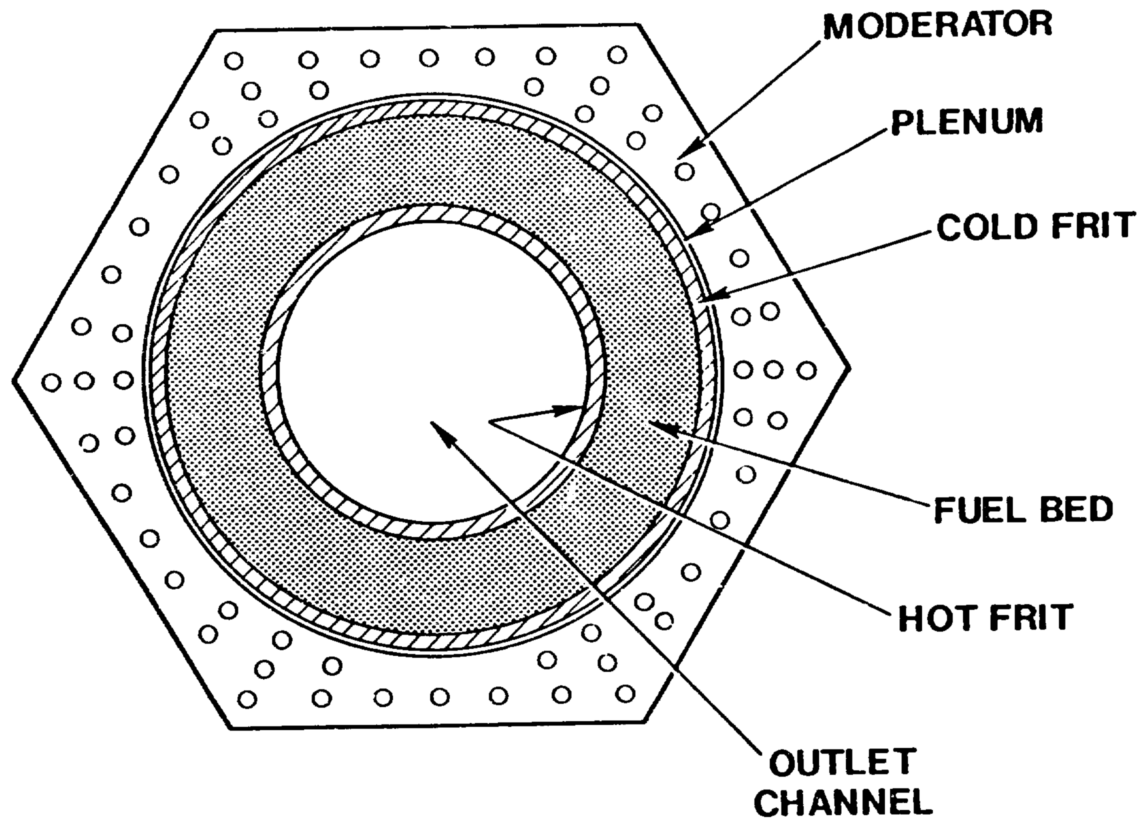

FIGURE 2

FUEL PARTICLE
OVERALL O.D. 500μm

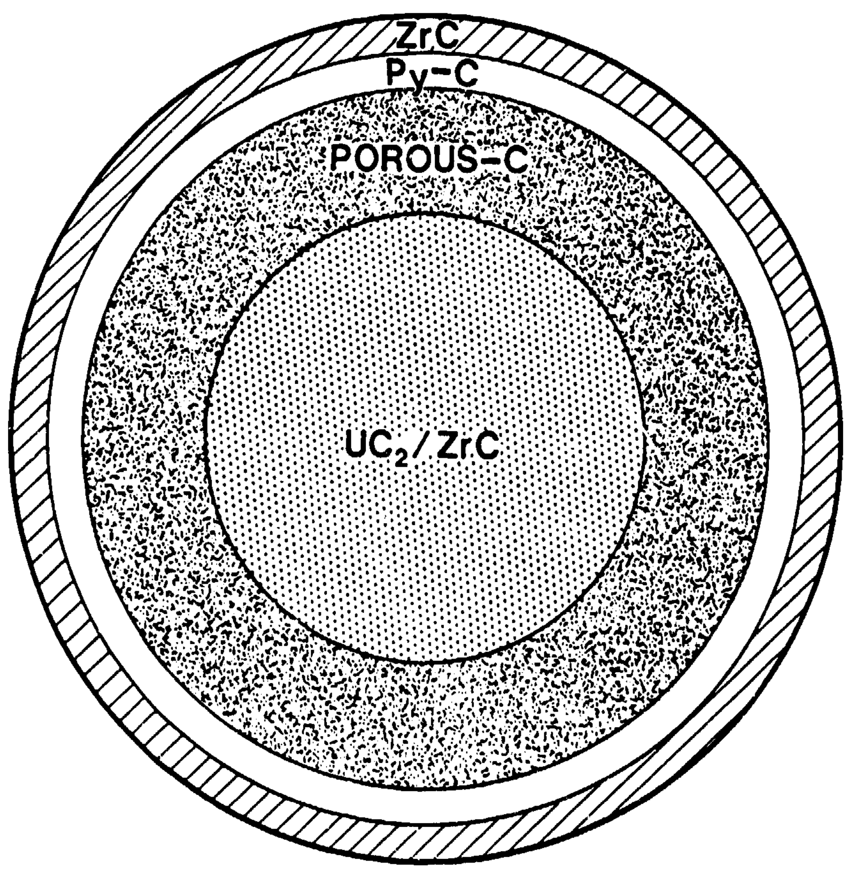

FIGURE 3