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WIRE CORE REACTOR FOR NTP

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I am going to talk about the wire core concept. This is not a new concept. It originated primarily by GE in the aircraft nuclear propulsion program, and this was a concept that they determined was the best for that particular application. However, the program was canceled, and AI (Atomics International) picked it up and did a fairly complete conceptual design study from 1963 to 1965, and even made some fuel. Nothing more has been done since that particular time.

You will notice there are some things that are missing. One is development planning. During this period, there was no development planning activities. Also, very little was done on safety. That does not imply that this concept is not safe. There are some very good safety features, but it does need to be updated to the current safety criteria.

The wire core is a system that has a thrust of 205,000 pounds -- we did not have the time or resources to characterize a system in the 75,000 pound category. A wire core consists of a fuel wire with spacer wires (Figure 1). It's an annular flow core. It has a central control rod. There are actually four of these, with beryllium solid reflectors on both ends and all the way around.

Figure 2 shows some details of the wire core. The wire diameter is 34 mils; about the size of a paper clip. The cladding, which is a tungsten rhenium alloy, varies in thickness from 2 to 7 mils depending on where it is in the radial direction of the core. The spacing is about 70 mils but that is a also variable. The fuel used was uranium nitrate. Figure 3 is a cross-section of the core just to show the size for this 205,000 lbs. of thrust. The core diameter is 24 inches with an 8-inch diameter central hole.

Figure 4 is the sketch of the overall engine. Most of the work during this study was done on the reactor and not on the engine. It is a bleed cycle with the hot gas driving the turbine. The outlet gas temperature here is 5000 degrees fahrenheit. Figure 5 is a summary of the performance with a block diagram of the engine cycle. The thrust is 205,000 lbs., which consists of thrust from the main nozzle, plus the exhaust from the pump nozzle. The actual specific impulse is 930 seconds.

Figure 6 is a breakdown of the reactor-only weight, and it includes the shield. You can see a significant portion is the gamma shield material. The total mass of this particular reactor here is 11,000 pounds.

Figure 7 shows engine weight vs. thrust. As previously mentioned, most of the work was performed for the reactor, so a range of values is shown. At 75,000 pounds thrust, the engine will weigh between 7000 and 9000 pounds.

The fuel element is a wire configuration. Figure 8 shows a technique used to fabricate this particular fuel element. They started with an 8 mil tungsten wire, and braided the wire into 125 mil diameter tubes. Then they packed 4 mil-sized UN fuel particles, coated with tungsten rhenium, inside the tubes. The tube was vapor-deposited with tungsten so that all the pores in the wire mesh were filled with tungsten. This tube was then swaged from 125 to 75 mils and drawn down to 35 mil diameter wire.

The wire core reactor has a high power density at the inlet of the core where the hydrogen is very cold. By controlling the spacing with the cladding thickness, one can obtain very low Delta-T's within your fuel element. The cladding thickness varies from 3 to 7 mils with a total diameter of the wire of 35 mils.

One of the problem areas of a radial flow reactor is flow distribution. In this particular reactor, half the flow comes in at the bottom and half at the top. It then turns and goes radially through the core.

If a reactor were built with constant axial spacing, one would obtain an axial temperature distribution as shown in Figure 9. This is the actual Delta-T divided by Delta-T average over the axial location. There are peaks up to 1.5, which is clearly unacceptable, while something in the order of 1.05 is required. The wire core reactor can be designed to control the Delta-T. Figure 10 shows what could be done to obtain a perfectly flat Delta T in the axial direction.

Figure 11 reviews some of the advantages of the wire core reactor. It has a very large heat transfer area. There are 570 square feet per cubic foot that can be compared to 120 for a typical NERVA reactor. The wire core reactor also has very large heat transfer coefficients. Radial flow also provides flow divergence, so when the gas is becoming hotter there is a much larger flow area. Separation of fuel and structure relies on the wire cladding for strength, not the fuel. There is a short heat path in the wire source, since the wire is only 35 mils in diameter. Compatibility of the fuel cladding and propellant is very important. The UN, tungsten and the hydrogen are all compatible at these high temperatures.

With radial flow the gas loads cancel in all directions. Also, high specific impulse, 5000 degree fahrenheit temperature capability, and restart capability are other advantages. One of the areas requiring development is the fuel element. There has been a lot of work on rhenium and uranium nitrate fuel and a review of this information is required to derive an adequate development program. Fuel fabrication development is also required, as is more work on safety.

WIRE CORE REACTOR

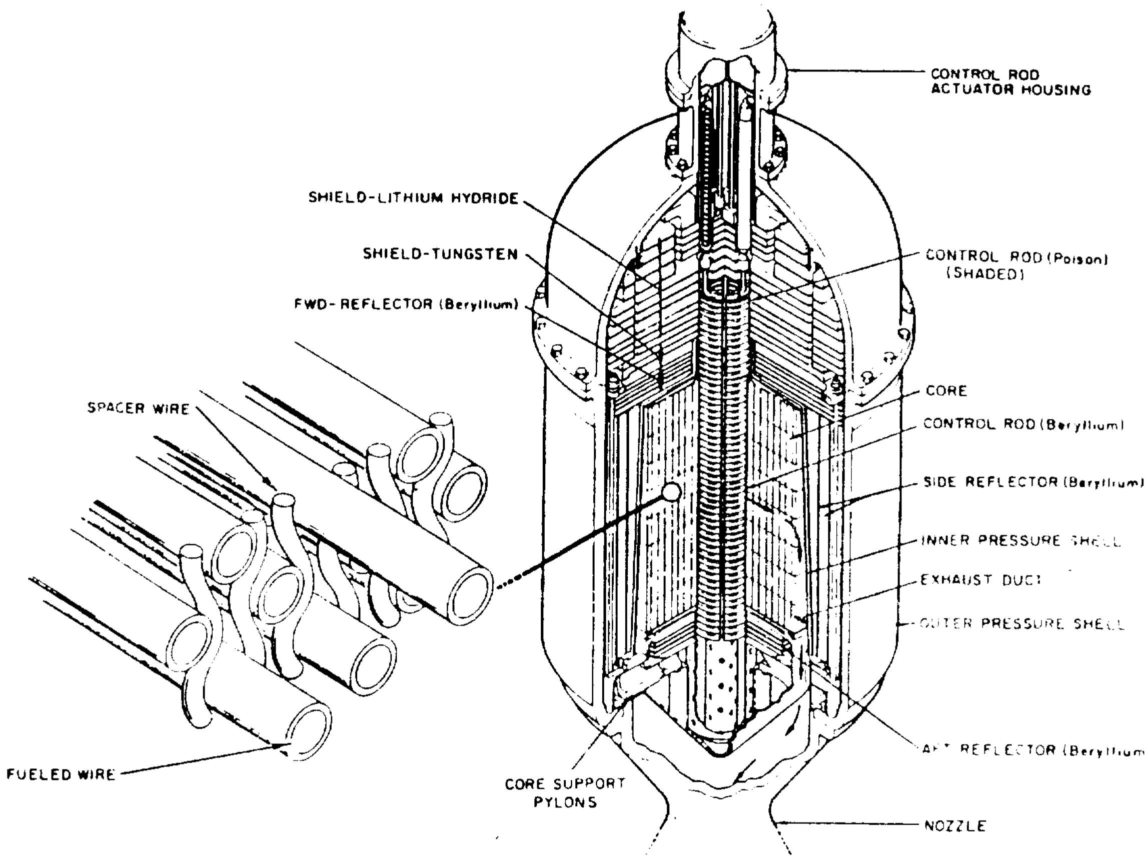

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Figure 1

REACTOR FUEL MATRIX

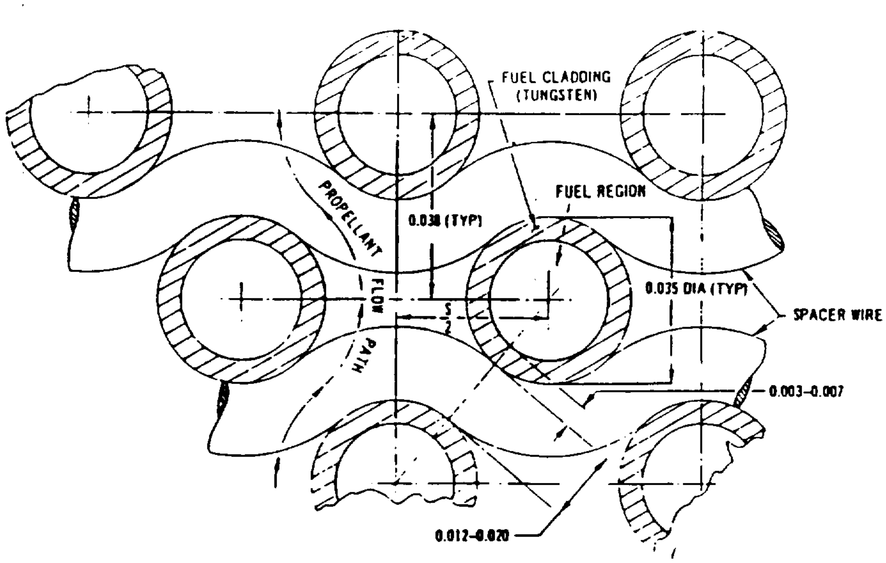

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Figure 2

REACTOR CROSS SECTION

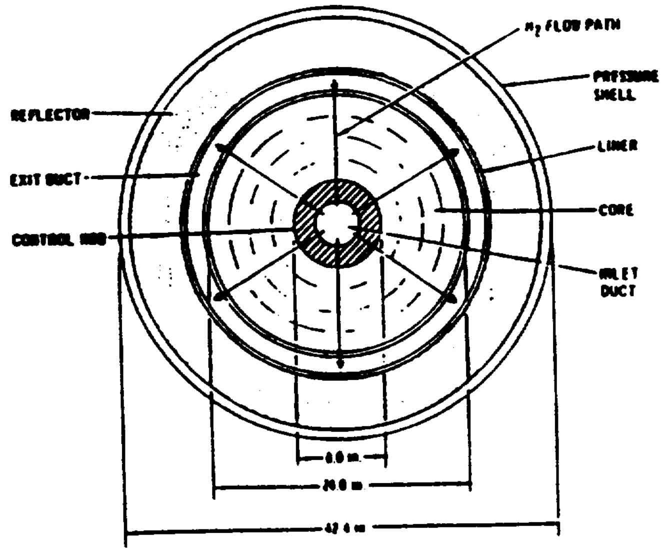

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Figure 3

NUCLEAR ROCKET SCHEMATIC FLOW DIAGRAM

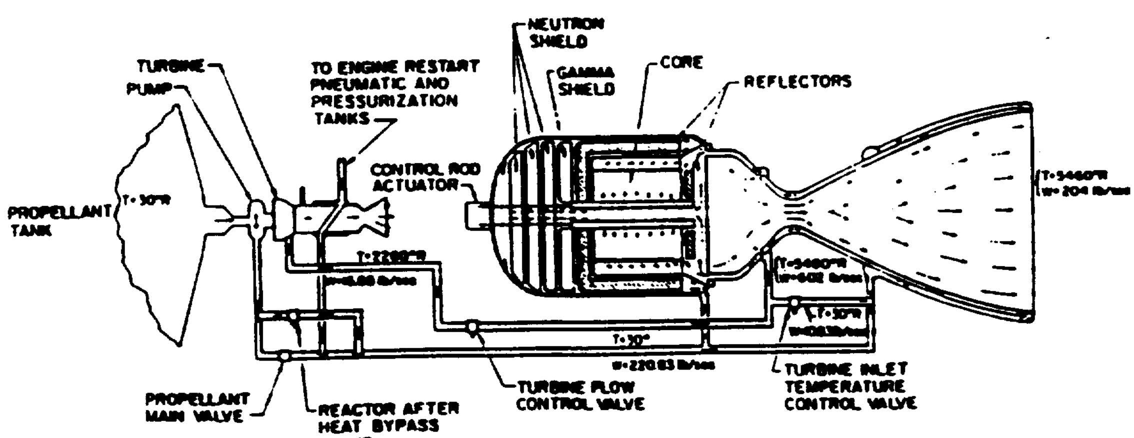

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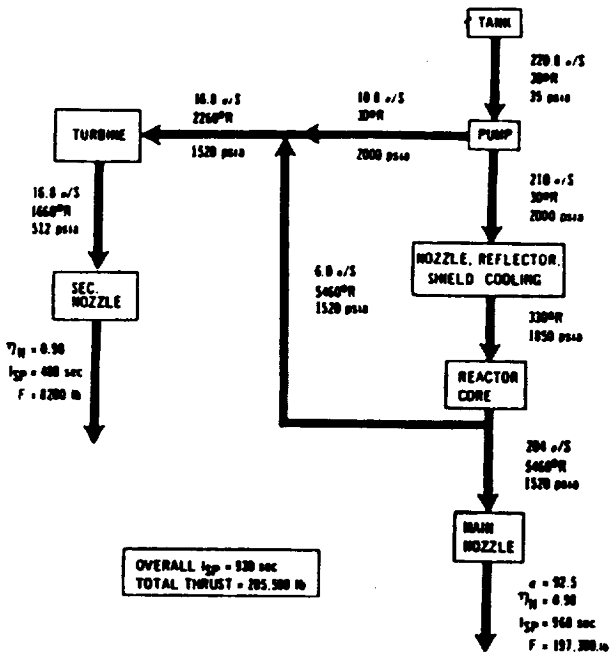
Figure 4

NUCLEAR ROCKET PERFORMANCE CHARACTERISTICS



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Thrust (lb)	205,500
Specific Impulse (sec)	930
Core Inlet Temperature (°R)	330
Core Exit Temperature (°R)	5460
Core Inlet Pressure (psia)	1850
Core Exit Pressure (psia)	~1500
Core Propellant Flow (lb/sec)	210
Core Thermal Power (Mw)	4400
Pump Cycle	Bleed
Turbine Flow (lb/sec)	17
Exit Area/Throat Area	92.5
Nozzle Efficiency	0.98

Figure 5

REACTOR/SHIELD ASSEMBLY WEIGHT BREAKDOWN

205,500 LB THRUST

	Pounds
Active Core	3,440
Reflectors	2,000
Gamma Shield	2,330
Neutron Shield	540
Control and Actuators	420
Outer Pressure Shell	935
Inner Pressure Shell	560
Core Rear Support	250
Core Front Support	350
Core Sheath	360
Total Weight	11,185

Figure 6

PREDICTED ROCKET ENGINE WEIGHT VS THRUST

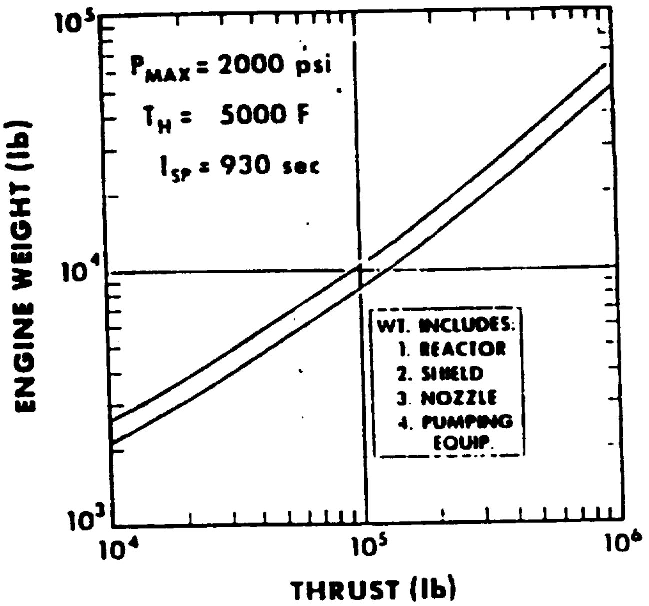
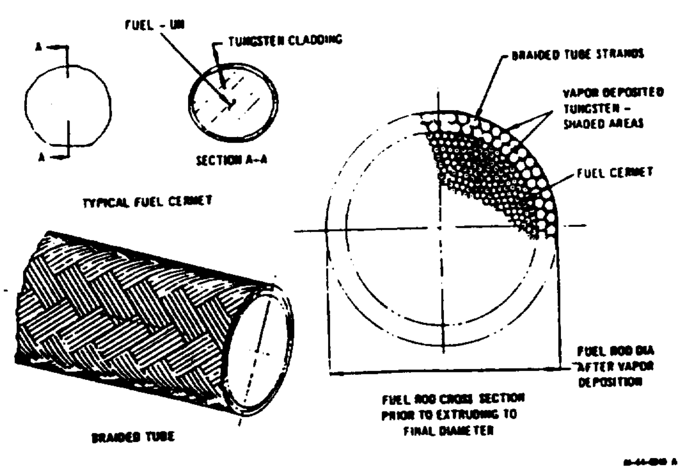


Figure 7

WIRE FUEL FABRICATION



MAKING FUELED WIRE

- Obtain 8 mil Tungsten Wire
- Braid Wires Into 125 mil diameter Tube
- Obtain 4 mil Size UN Fuel Particles
- Coat Fuel Particles With Tungsten
- Fill Braided Tube With Coated Fuel
- Vapor Deposit Tungsten on Filled Tube
- Swage Tube From 125 to 75 mils
- Draw to 35 mil diameter Finished Wire

Figure 8

CORE POWER, FLOW, PRESSURE DROP, AND TEMPERATURE DROP DISTRIBUTION

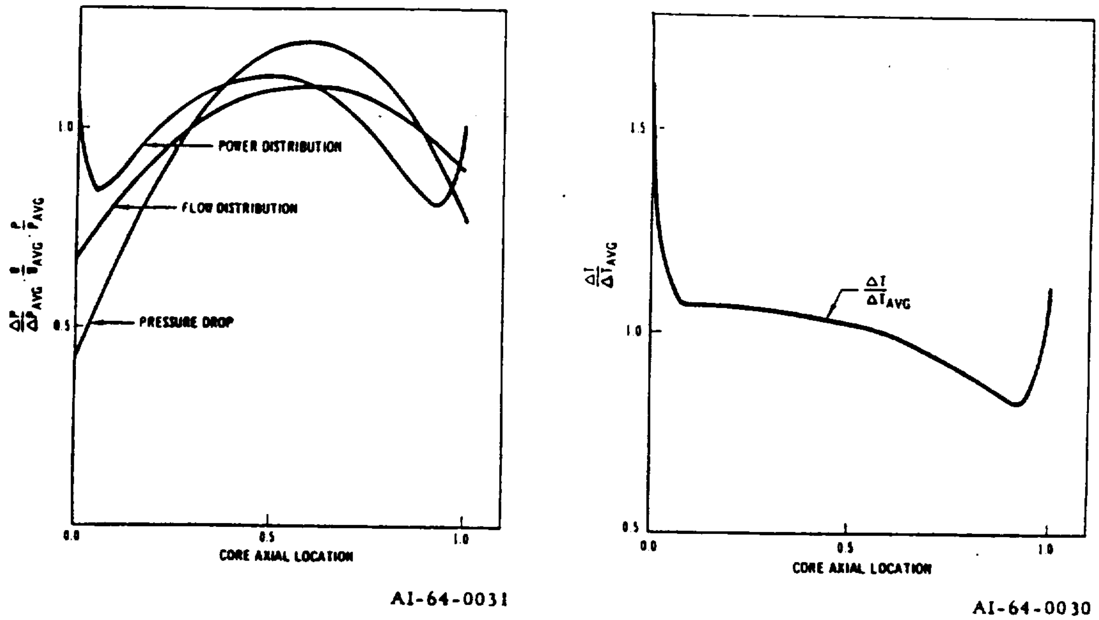


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Figure 9

CORE FUELED WIRE SPACING AND SOLIDITY VARIATION FOR UNIFORM H_2 TEMPERATURE RISE

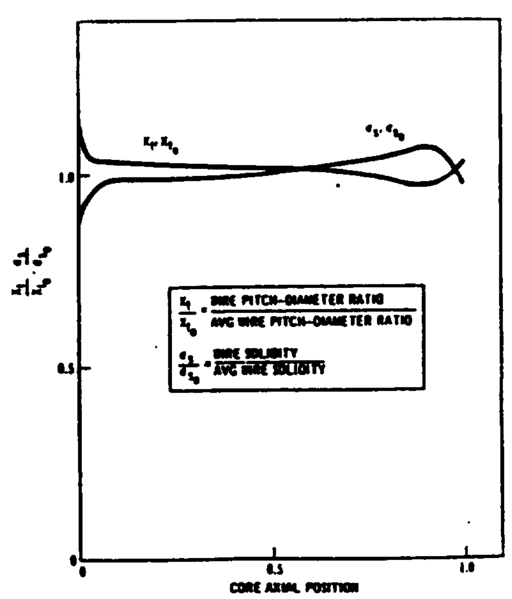

Figure 10

ADVANTAGES OF WIRE CORE REACTOR

- LARGE HEAT TRANSFER AREA
  - 570 FT^2/FT^2 (19 CM^2/CM^3) COMPARED TO 120 FT^2/FT^3 (4 CM^2/CM^3)
- LARGE HEAT TRANSFER COEFFICIENT
  - AVERAGE FILM COEFFICIENT = 8500 BTU/FT^2-HR-·F (4.8 W/CM^2-·C)
- RADIAL FLOW DIVERGENCE
  - MOVE HEAT TRANSFER TO OUTER HOTTER WIRES
- AXIAL POWER SHAPING
  - AXIAL SPACING BETWEEN FUELED WIRES
- SEPARATION OF FUEL AND STRUCTURE
  - RELIES ON THE WIRE CLADDING FOR STRENGTH (NOT THE FUEL)
- SHORT HEAT PATH IN WIRE
  - LOW CENTER TO SURFACE TEMPERATURES
- COMPATIBLE FUEL, CLAD, AND PROPELLANT
  - UN, W, AND H_2 COMPATIBLE AT ELEVATED TEMPERATURES
- GAS LOADS CANCEL
  - RADIAL GAS FLOW RESULTS IN CANCELING OF GAS LOADS
- HIGH SPECIFIC IMPULSE
  - ISP = 930 SEC
- RESTART CAPABILITIES
  - METALLIC CONSTRUCTION INHERENTLY RESISTANT TO THERMAL SHOCK

Figure 11