N92-11102

PELLET BED REACTOR FOR NUCLEAR PROPELLED VEHICLES: II. MISSIONS AND VEHICLE INTEGRATION TRADES

V. E. (Bill) Haloulakos
McDonnell Douglas
Huntington Beach, CA

As Mohamed said, I will be discussing the mission and vehicle integration trades and so I am not going to say anything about reactors, neutronics or anything else. The issue here is that you can make a reactor or an engine, but unless you can hang it into a vehicle it won't go anywhere. So I would like to address some of these issues.

You have to go through all of these factors (Figure 1) before you know if the vehicle can fly. You have to look at the whole vehicle. You can have all kinds of efficiencies you want in the reactor, but if it doesn't fly, it won't go anywhere.

Here are some of the trades done back then during the NERVA program (Figure 2). What shape is your tank and where do you put your rocket engine and your reactor? You go in with some distance to avoid the radiation (this will cause feed system problems), then you begin to play with geometry; the optimum that came out is a 15 degree cone angle.

Figure 3 shows the mass and radiation breakdown for the shielding from the previous chart that I showed you. The 15-degree cone angle gives you the lowest radiation for a given shield mass. So, based on this chart it was decided that we would pick the 15-degree cone angle as the bottom of the tank.

There were many other trades that were done. Here is what the problem looked like; you are not going to Mars and get rid of the reactor, you are going to fire it, shut it down, and then you have to cool it. When you use propellant as coolant, you lose specific impulse. The trades done back then show what happens to your specific impulse as you cool the reactor down (Figure 4). So you have to go through these trades as well.

As to radiation maps (Figure 5), I am not a radiation expert, but these were done back for the NERVA engine. You have neutron flux, you have gamma radiation, a reference point up there and we are talking about a 1575 megawatt reactors operating for 53 minutes and so on. So all these factors have to be addressed.

Then as to what happens after shut down (Figure 6), you have a decay which goes as shown, and here is the radiation versus distance, which continues on, and so on.

In our present studies (Figures 7-9) we are moving from the 1960's to the 1980's and 1990's via computer programs. We had a very good correlation between the calculations from the old NERVA data that we got out of the design handbooks. The same thing was found for a small engine that was supposed to operate an ROTV out of the space shuttle, (if you can believe that) (Figure 7).

For a pellet bed reactor mission to Mars, just the other day one of our guys gave me these numbers (Figure 10). If you fly on May 11, 2018, taking 250 days for the total trip, with 30 days stay, these are your Delta-V breakdowns. So on the basis of this, we can take a thrust, an engine, and hang it on the vehicle and start calculating some system masses and see what happens.

This is what happens when you plot Delta velocity versus mass (Figure 11). The way we break things down is shown in Figure 12. We have a Delta velocity and a specific impulse of 1,000 seconds when we calculated with our program. We come up with a payload of 36 metric tons, the thrust is 315 kilo-Newtons. That's about 70,000 pounds or so, including the mass of the shield. This is the output. I must say this mass ratio is not payload fraction. Payload fraction is shown in Figure 13. This is for the top curve, the heaviest vehicle that we got and that's almost a half a million kilograms there. Pretty big stuff!

Looking at it parametrically in terms of payload fraction, we show that, as you demand more and more velocity out of a fixed performance, your vehicle becomes almost like the chemicals we have today, which have something like three to four percent payload fraction. This says that what you want to do is increase the specific impulse. And by the way, if you go to a single stage Delta V, which is like nine to ten kilometers per second with a nuclear vehicle, you begin to approach 25 percent of payload fraction.

I was talking to airplane people who design airplanes being flown for money and they say that of their takeoff weight, fuel is something like 40 percent. What we would like to do is drive the space vehicles in that direction.

We didn't do anything on cost for this workshop, but we did a lot of work on cost back in the 1970's. There is a whole bunch of reports that I sent NASA, and one written on February 1973 cost data, 1973 dollars. Oh, do they look good. I suggest that you take that to Congress when you go and talk to them.

BIBLIOGRAPHY

Bill Haloulakos
PeBR for Electric and Thermal Nuclear Propulsion

Acknowledgments

The development of the PeBR for electric and thermal nuclear propulsion missions has been performed by the University of New Mexico's Institute for Space Nuclear Power Studies. The System Trades and Performance Studies were performed at McDonnell Douglas Space Systems Company, Huntington Beach, CA; the contributions of T.M. Miller and J.F. LaBar are hereby acknowledged.

1. Alcoufee, R.E., F.W. Brinkley, D.R. Marr and R.D. O'Dell, "Users guide for TWODANT: A Code Package for Two-Dimensional, Diffusion-Accelerated Neutral-Particle Transport", Report No. LA-10049-M Rev. 1, UC-32, Los Alamos National Laboratory, Los Alamos, NM (1984).

2. Altseimer, J.H. et al "Operating Characteristics and Requirements for the NERVA Flight Engines", J. Spacecraft, 8(7):766-773 (1971).

3. Bennett, G. "Nuclear Thermal Propulsion Program Overview," NASA Nuclear Thermal Propulsion Workshop, Cleveland, OH 10-12 July, 1990.

4. Durham, F.P. "Nuclear Engine Definition Study Preliminary Report", LA-5044-MS, Vol. I-III, Los Alamos Scientific Laboratory (1972) Los Alamos, NM.

5. El-Genk, M.S., A.G. Parlos, J.M. McGhee, S. Lapin, D. Buden and J. Mims, "System Design Optimization for Multimegawatt Space Nuclear Power Applications", J. Propulsion and Power, (2)"194-202, 1990a.

6. El-Genk, M.S., N.J. Morley, and V.E. (Bill) Haloulakos, "Pellet bed Reactor for Nuclear Propelled Vehicles", NASA Nuclear Thermal Propulsion Workshop, Cleveland, OH 19-22 June 1990.

7. El-Genk, M.S. "Pellet Bed Reactor Concept for Space Propulsion", NASA Nuclear Electric Propulsion Workshop, Pasadena Convention Center, Pasadena, CA 19-22 June 1990.

8. Gordon S. and B.J. McBride. "Computer Program for Calculations of Complex Chemical Equilibrium Composites, Rocket Performance Evident Reflected Shocks and Chapman-Jouguet Detonations", NASA SP-273, NASA Lewis Research Center, Cleveland, OH, March 1976.

9. Haloulakos V.E. and C.B. Coehmer. "Nuclear Propulsion: Past, Present, and Future", McDonnell Douglas paper No. MDC H2642, Trans. 5th Symposium on Space Nuclear Power Systems, CONF-880122-SUMMS, Albuquerque, NM, 11-14 January 1988.

10. Nabielek, H. et al. "Fuel for Pebble-Bed HTRs", J. Nuclear Engineering and Design, 78:155-166, (1984).

11. Stansfield, O.M., F.J. Noman, W.A. Simon, and R.F. Turner. "Interactions of Fission Products and SiC in TRISO Fuel Particlea: Limiting HTGR Design Parameter", Report No. Ga-A17183-UC-77, General Atomis Technologies, San Diego, CA, U.S. Dept. of Energy, San Francisco, CA, 1983.

DESIGN TRADE STUDIES

- Propellant Tank Geometries
  - Weight
  - Volumetric Efficiency
  - Radiation Considerations
- Skirts and Interfaces
- Handling, Transportation and Launching Factors
- Reusable vs Expendable
- Refueling, Refurbishing
- Start, Shutdown, Restart Factors
  - Fluid Transients
  - Heat Soak Back
  - Post Shutdown Cooling
    - — Performance Loss/Recovery

Figure 1

CONVENTIONAL TANK CONFIGURATION

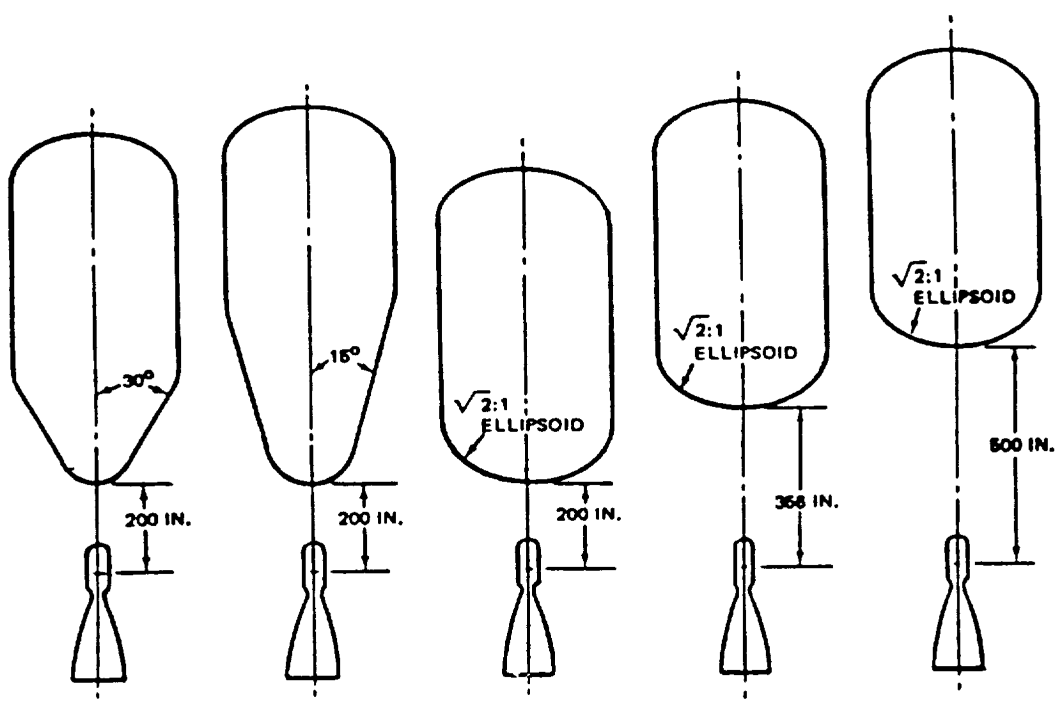

Figure 2

SHIELD WEIGHT REQUIREMENTS FOR CONVENTIONAL TANK CONFIGURATIONS

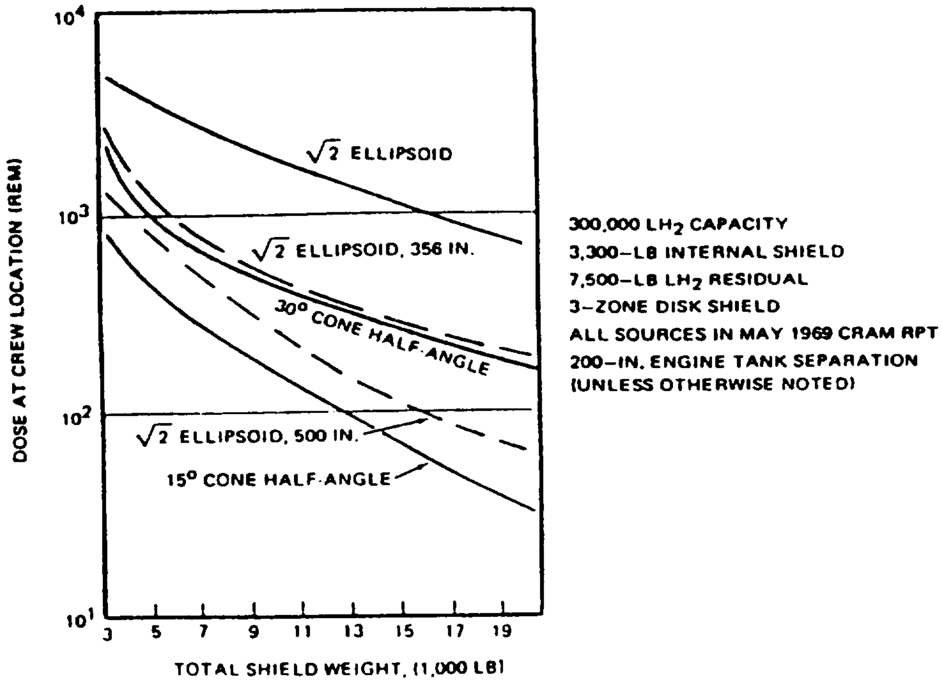

Figure 3

EFFECTIVE SPECIFIC IMPULSE

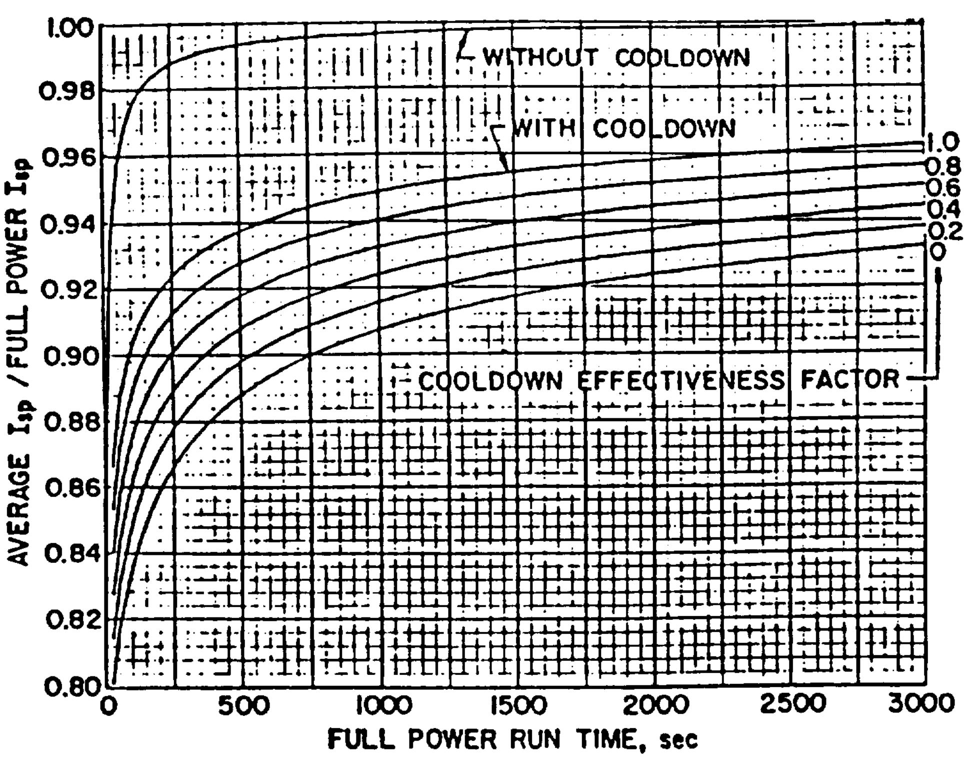

Figure 4

RADIATION MAP

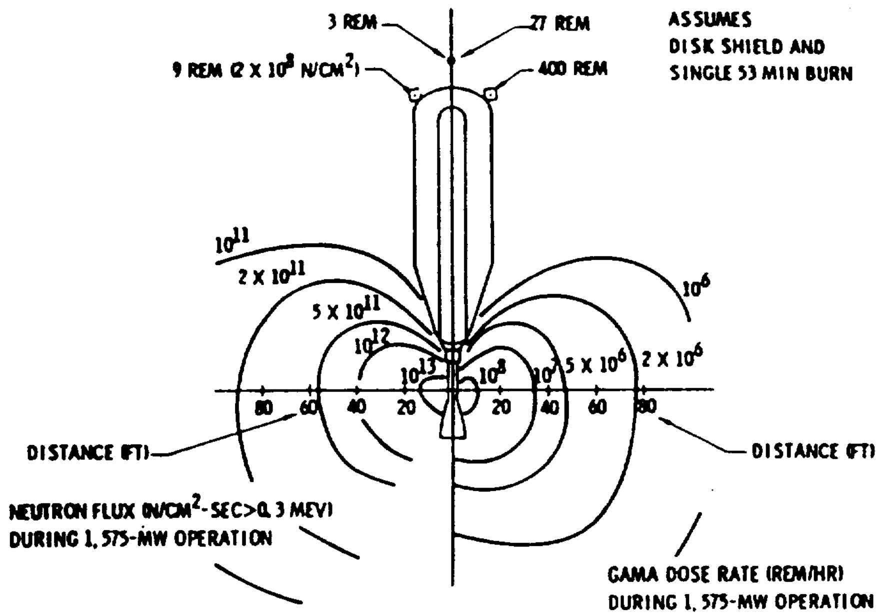

Figure 5

DOSE RATE AFTER SHUTDOWN

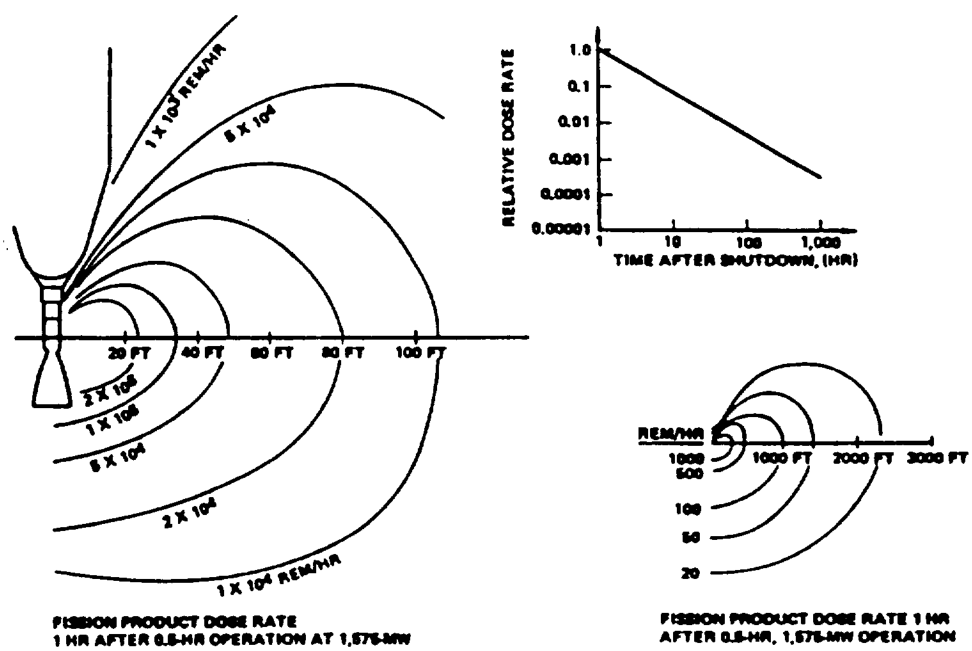

Figure 6

CLASS 1 SINGLE-MODULE HYBRID RNS

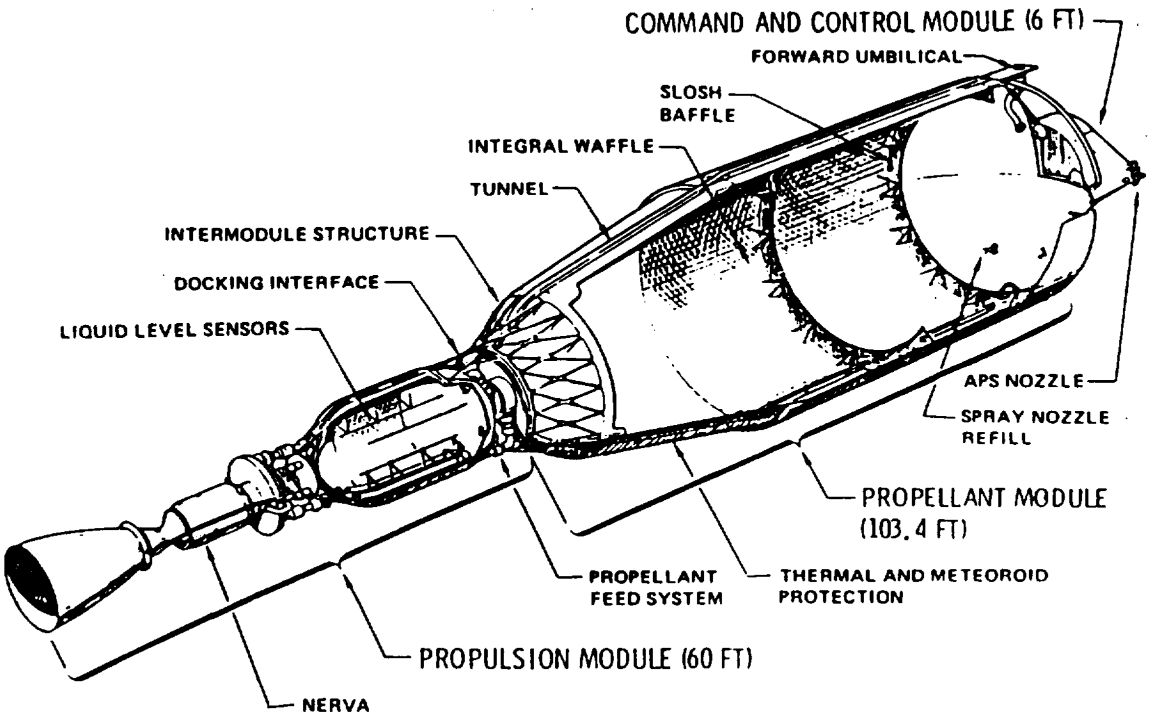

Figure 7

SPACE TRANSFER VEHICLE DESIGN DATA

LEO to GEO With Return Mission Data : Payload Mass 36,000 kg; Velocity Increment 9,000 m/s

	CRYOGENIC (O2/H2)		NUCLEAR FISSION	FUSION	
ROCKET ENGINE	6 RL - 10's	J - 2	LANL ALPHA 2	NEW	NE
Thrust (kN)	400.3	902	71.7	100	1
Specific Impulse (s)	450	429	860	3,500	1
Burn Time (s)	3,675	1,850	12,835	5,766	1
MASS BREAKDOWN					
PROPELLANTS (kg)	333,291	396,423	109,120	16,792	99,
Fuel (LH2)	51,275	60,988			
Oxidizer (LOX)	282,015	335,435	-	-	
PROPELLANT TANK(S)					
Total Volume (m3)	970	1,154	1,748	269	1,6
Mass (kg)	8,156	9,701	11,746	1,808	10,7
PRESSURIZATION (He system) (kg)	1,374	1,635	1,979	305	1,8
ENGINE (kg)	792	1,579	2,567	17,168	80,9
MISCELLANEOUS (kg)	3,411	4,058	4,913	756	4,4
TOTAL VEHICLE MASS (kg)	383,024	449,394	166,326	72,828	233

Figure 8

SPACE TRANSFER VEHICLE DESIGN DATA

LEO - GEO - LEO Mission ; Mpl = 36,000 kg ; Del V = 9 km/s ; Burn Time = 3675 s

ROCKET ENGINE		CRYOGENIC , 6 RL-10's	NUCLEAR , 4 ALPHA 2's	FUSION , Me=12 (Isp)
Thrust	(kN)	400	278	208
Specific Impulse	(s)	450	860	2500
MASS BREAKDOWN				
PROPELLANTS	(kg)	333,291	134,548	34,685
Fuel	(LH2)	51,275		
Oxidizer	(LOX)	282,015	-	-
PROPELLANT TANK(S)				
Total Volume	(m^3)	970	1,937	499
Mass	(kg)	8,156	10,849	2,797
PRESSURIZATION				
He System	(kg)	1,374	1,828	471
ENGINE(S)	(kg)	792	10,270	30,000
MISCELLANEOUS	(kg)	3,411	4,538	1,170
TOTAL VEHICLE MASS		383,024	198,033	105,123

Figure 9

MCDONNELL DOUGLAS — Space Exploration Initiative

MARS MISSION ΔV SUMMARY

- TRANS-MARS INJECTION : 4.71 km/s
- MARS CAPTURE : 9.03 "
- TRANS-EARTH INJECTION : 9.93 "
- EARTH CAPTURE : 7.20 "

TOTAL : 30.87 km/s

- LAUNCH DATE : 11 MAY 2018
- TOTAL TRAVEL TIME: 250 DAYS
- MARS STAY TIME: 30 "

Figure 10

TOTAL OTV MASS vs. VELOCITY INCREMENT

PELLET BED REACTOR NTR

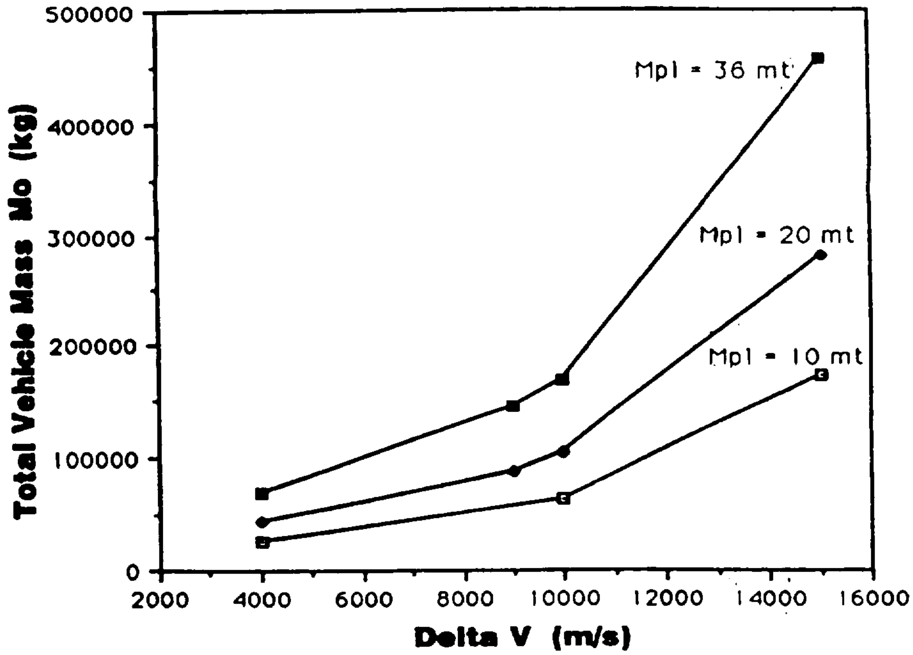

Figure 11

SAMPLE PELLET BED NUCLEAR OTV MASS BREAKDOWN

Input Parameters		
Delta V (ΔV)	15,000	m/s
Specific Impulse	1000	s
Payload Mass	36,000	kg
Thrust	315	kN
Engine Mass	1,875	kg
Shield Mass	4,000	kg
Calculated Parameters		
Mass Ratio R	4.611	
Propellant Fraction (Mp/Mo)	0.857	
Payload Fraction (Mpl/Mo)	0.086	
Tank Volume	5,249	m^3
Burn Time	170	min
Component Mass Breakdown		
Propellant (H_2)	364,568	kg
Propellant Tank	34,703	kg
Thrust Structure	649	kg
Pressurization System (He)	4,365	kg
Meteoroid/Thermal	9,164	kg
Total Vehicle Mass	455,324	kg

Figure 12

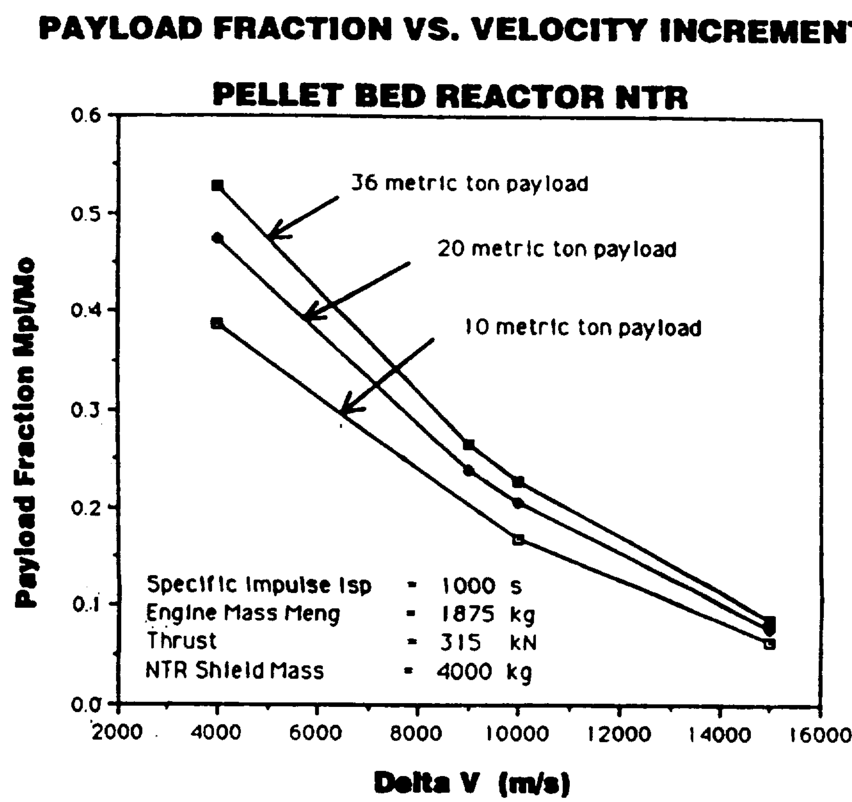
PAYLOAD FRACTION VS. VELOCITY INCREMENT
PELLET BED REACTOR NTR
36 metric ton payload
20 metric ton payload
10 metric ton payload
Specific Impulse Isp = 1000 s
Engine Mass Meng = 1875 kg
Thrust = 315 kN
NTR Shield Mass = 4000 kg
Payload Fraction Mpl/Mo
0.6
0.5
0.4
0.3
0.2
0.1
0.0
2000
4000
6000
8000
10000
12000
14000
16000
Delta V (m/s)

Figure 13