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# NUCLEAR THERMAL/NUCLEAR ELECTRIC HYBRIDS

B. D. Reid
Battelle Pacific Northwest Laboratory
Reactor Technology Center

First I would like to describe the nuclear thermal and nuclear electric hybrid. The concept isn't new; as our previous speaker indicated, there had been some work done in the early 1970's, and I will briefly describe some of that again.

We evaluated a hybrid concept, and I will be describing its specifications and its mission performance. Then, as requested by our workshop organizers, I will discuss technical status, development requirements, and we, like everyone else, will provide some optimistic cost estimates.

Essentially (Figure 1), we see the hybrid working as a concept whereby you have both thermal propulsion and electric propulsion. We see this concept being used when you would use a thermal propulsion, high thrust thermal propulsion for your trans-Mars/trans-Earth injection burns, and using electrical propulsion in transit (Figure 2).

This is all using one reactor. There are differences in the reactor performance when it's a one mode versus the other. In the thermal propulsion mode, the reactor is operating at, let's say, 1500 megawatts. In the electric production mode, it's of the order of 2 to 3 percent of that, which translates to about 35 megawatts thermal.

In looking at hybrids there are options in the design. One option uses common heat transfer passages, while the other uses independent heat transfer passages. There are pluses and minuses to each of these options. I will show a schematic of each of them to explain them a little more fully. With the independent heat transfer concept, you do have the possibility of providing electrical power during your thermal propulsion cycle.

This is a rough schematic of a common cycle hybrid (Figure 3). During open cycle propulsion, you close two valves and it essentially operates just like a standard NERVA. In the power production mode, the other two valves are closed. Argon is used both in the closed cycle power conversion and to provide your propellant for your electric propulsion; in this case we have chosen MPD thrusters.

Here is an independent cycle (Figure 4). In this schematic for the open cycle propulsion, the hydrogen flows through the reactor, and again the open cycle propulsion just like a NERVA. During the power conversion cycle, you can operate this cycle independent of the open cycle propulsion, using the argon through separate cooling passages and also through your MPD thrusters.

With this slide I am going to repeat some information that you already have seen today (Figure 5). As part of the NERVA/ROVER program, dual mode reactors were looked at. The primary incentive was to reduce propellant losses which were required to address decay-heat removal.

In this case the NERVA concept was operating at 365 megawatts in its thermal propulsion mode. For the electrical propulsion, it was operating at only 1 megawatt with only approximately 25 kilowatts electricity to an organic Rankine cycle. For this there were very few engine modifications required, primarily materials.

This is another cartoon of the same concept that you saw previously (Figure 6). During the thermal propulsion mode, the power conversion cycle is essentially cut off and the turbine is driven by hydrogen flow through the core support tie-tubes. When the reactor is not in the thermal propulsion mode, this circuit could be energized for power conversion.

We evaluated a hybrid concept for the manned Mars mission. It is based on a 1500 megawatt NERVA with 850 seconds specific impulse. We chose Brayton cycle with argon, with 8 megawatts electricity, and 35 megawatts thermal. And again, we are using the MPD thruster at 5000 seconds specific impulse. In the concept that we have chosen here during thermal propulsion (Figure 7), two valves are closed: it operates just like a standard NERVA. During the power conversion cycle, the other two valves are closed, and we have a valve in the nozzle.

Now, we recognize there are some significant challenges with this, and we were a little loath to put this up here because we thought it might fail the "snicker" test. But after careful study, we think that it's a concepts that will work. Again, the advantage with this type of cycle is that you can achieve a reasonable power production with this concept. The earlier concepts were very limited in the power you were able to obtain from the core because you had very limited heat transfer surfaces. This concept operates at about 1400 Kelvin, which is well below the operating temperature of the core in the thermal propulsion mode. The Brayton cycle will operate at about 150 psi.

This chart shows some of the performance specifications of our concept (Figures 8 & 9). These thrust/weight numbers here, I would like to caution you, are only for the base reactor. The lifetime for this concept in the thermal propulsion mode is similar to NERVA, or approximately 10 hours. In the electric propulsion mode, we have convinced ourselves that you have a life of at least 2 years, which is sufficient for the reference mission. Figure 9 is a mass breakdown. This is for a mission that was less than 600 days, 555 days to be exact.

One of the advantages of the hybrid concept (Figure 10) is that you do have the ability to provide electricity for housekeeping loads and, with space power beaming, you have the ability to provide significant power to meet other mission objectives such as supporting a base on the Martian surface.

As noted, this concept is primarily based on the NERVA technology, and there have been a lot of improvements in that technology that can be incorporated here, primarily in fuels and materials for nozzles and core materials. We believe that the primary uncertainties with this concept are going to lie with the other part of the power conversion system; with the Brayton cycle.

Figure 11 summarizes in chart form our anticipated technology readiness. As most speakers have touched on today, the reactor is at readiness level approaching 6. Our greatest uncertainty lies in integrating the two power conversion cycles, and we have identified that accordingly (Figure 12).

Here is our cost estimate (Figure 13). It's a rough order of magnitude, and it's as optimistic as the next guy's.

Summing up, in our mission benefits (Figure 14), we have identified modest reductions in trip time compared to the nuclear thermal only, at the same masses. Said another way, you have reduced masses compared to nuclear thermal options with similar trip times. Now, a key to all this is that incorporation of the dual mode concept into a thermal reactor, you must not significantly degrade the specific impulse of your thermal reactor, or you have lost everything that you are going to gain with your electric propulsion. So, a key in coming up with this design is making sure that you haven't hurt yourself in Isp.

As to safety issues, these are primarily those associated with NERVA, and other people can probably address those more capably than I. However, there is a minimal additional risk associated with incorporating this additional system that we can't ignore. It does provide some finite increase in risk.

## BIBLIOGRAPHY

Bruce Reid

Dual Mode Hybrid Concept


1. Altseimer, J.H. et al.. "Operating Characteristics and Requirements for the NERVA Flight Engine"; J. Spacecraft, Volume 8, July 1971.

2. Holman, R.R., and B.L. Pierce. "Development of NERVA Reactor for Space Nuclear Propulsion"; AIAA 86-1582, June 1986.

## PNL NTP/NEP CONCEPT DESCRIPTION

- Based on 1500 MWth NERVA for thermal propulsion
  - 850 Isp using hydrogen as propellant
- Generation of 8 MWe from Brayton cycle at 35 MWth during electrical propulsion
  - Employs MPD thruster at 5000 Isp using argon as propellant and Brayton cycle working fluid

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Figure 1

## NTP/NEP HYBRID DESCRIPTION

- Nuclear thermal propulsion for TMI and TEI burns supplemented by nuclear electric propulsion during transit
- Characteristics of NTP/NEP Hybrid
  - Considerable power differences between open cycle mode and closed cycle mode
  - Option for common or independent heat transfer passages in reactor
  - Possibility of providing electrical power while in thermal propulsion mode

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Figure 2

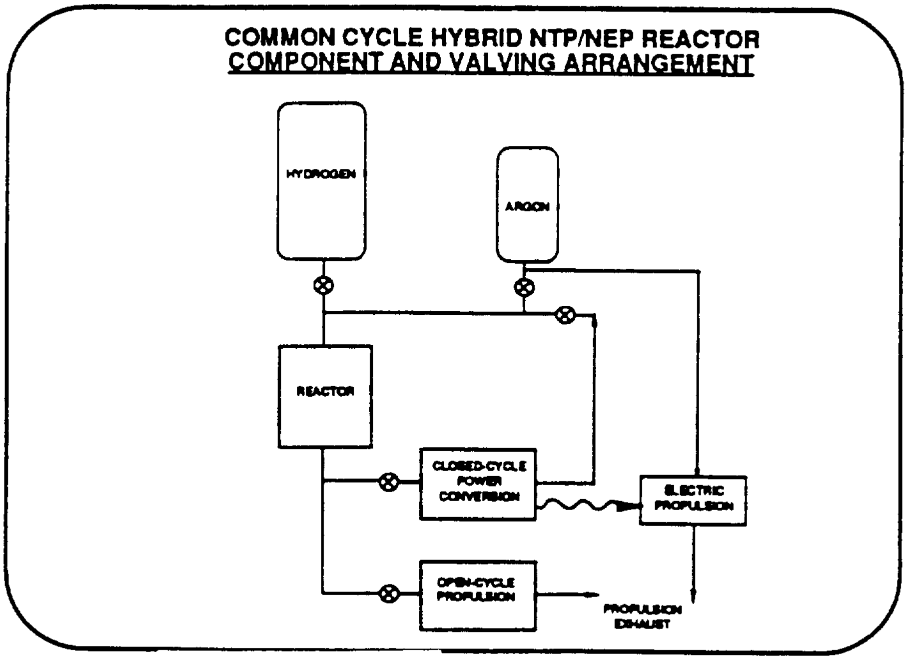


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Figure 3

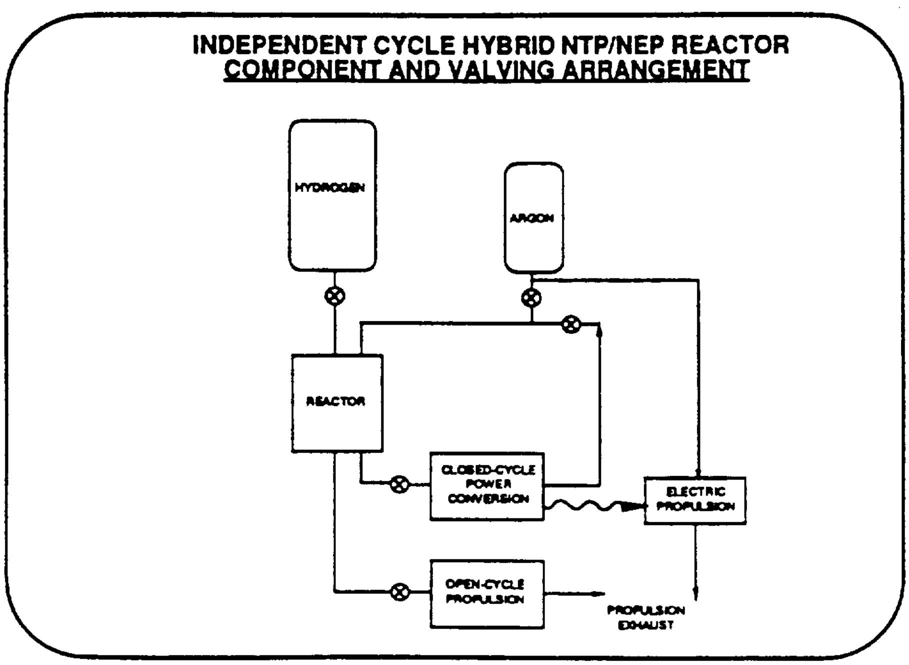


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Figure 4

## HISTORY OF NTP/NEP CONCEPTS

- Dual mode Nuclear Rocket proposed during ROVER Program in early 1970's
- Based on 365 MWth NERVA
  - Operating at 1 MWth generating approximately 25 kWe from Rankine Cycle
- Concept required few engine modifications
  - Change reactor dome design
  - Change tie tube support line materials

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Figure 5

## EARLY DUAL MODE NUCLEAR ROCKET CONCEPT

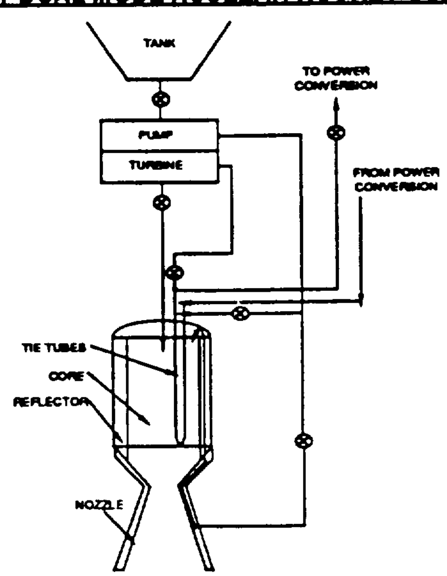


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Figure 6

## PROPOSED HYBRID NTP/NEP REACTOR CONCEPT

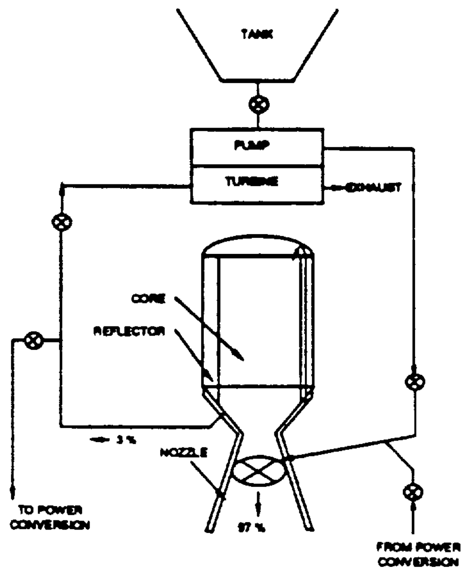


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Figure 7

## NTP/NEP HYBRID PERFORMANCE

**Propulsion:**

| | | |
|---|---|---|
| Thermal | 850 Isp | 75,000 lb thrust |
| Electric | 5000 Isp | 15 lb thrust |

**NTP Thrust/Weight**

| | |
|---|---|
| With shield | 4.7 without electric thrust |
| Without shield | 7.7 without electric thrust |

**Lifetime:**

Thermal - approximately 10 hours

Electric - greater than 2 years

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Figure 8

## NTP/NEP HYBRID PERFORMANCE
(CONTD)

IMLEO:

| | |
|---|---|
| Payload | 124 MT |
| Propulsion Subsystem* | 16 MT |
| Propellent (hydrogen / argon) | 384 MT |
| Total | 524 MT |

*reactor, shield, radiator, armor, thrusters

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Figure 9

## MISSION PERFORMANCE OF NTP/NEP HYBRID

- Trip time
- Initial Mass in Low Earth Orbit (IMLEO)
- Increased commonality and redundancy
  - Electric production for housekeeping loads
  - Redundant / alternate means of propulsion
  - Electric production for surface application through space power beaming

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Figure 10

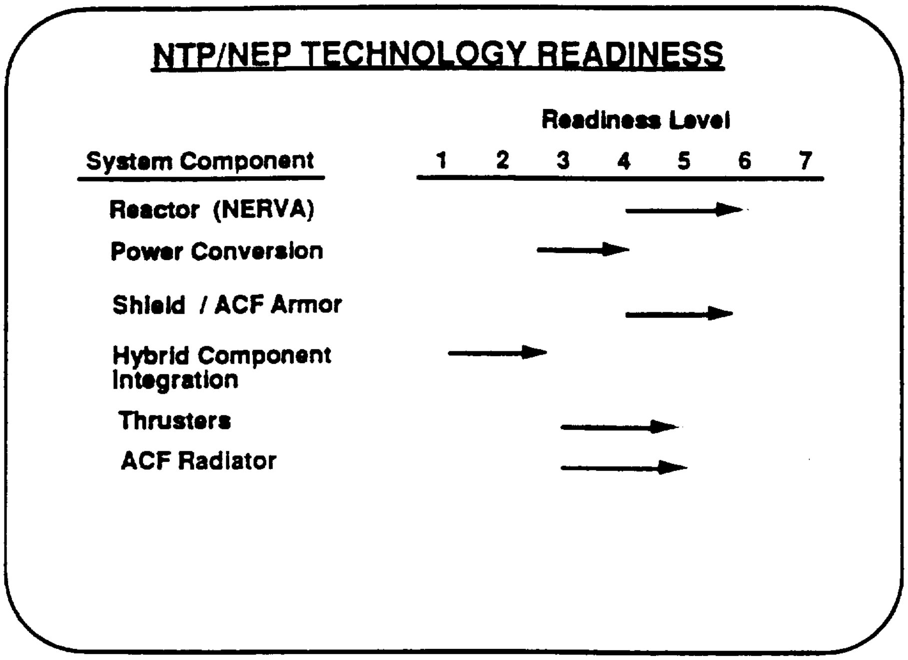


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Figure 11

## TECHNICAL STATUS AND ESTIMATED COST

- Reactor technology based on proven NERVA Technology from early 1970's

Therefore:

- Principal technology uncertainties and primary development costs associated with power conversion and integration of power and propulsion modes

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Figure 12

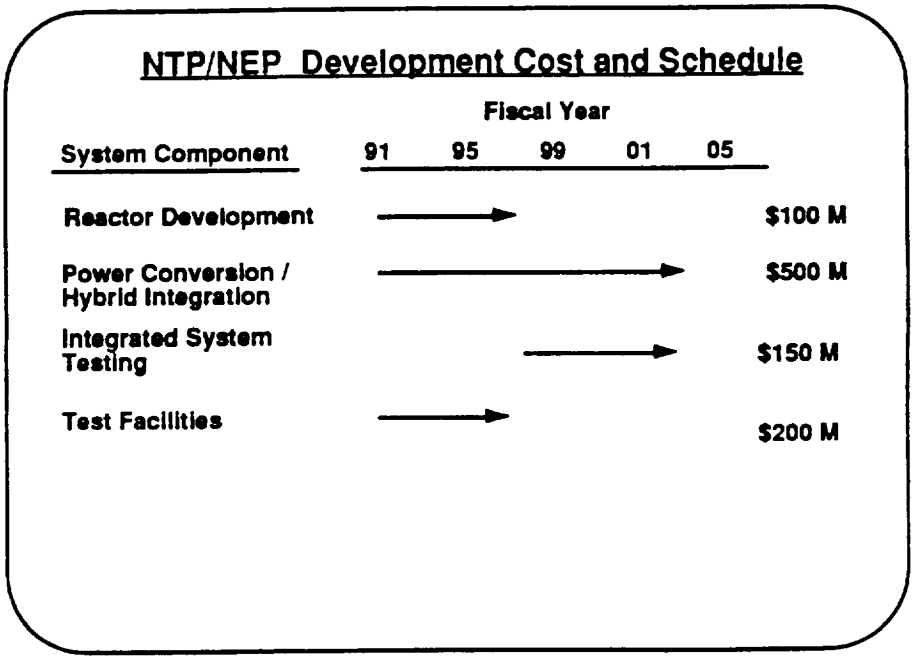


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Figure 13

## Conclusions ON NTP/NEP HYBRID

**Mission Benefits**

- Reduced trip time compared to NTP options with only propulsion mode
- Reduced IMLEO compared to NTP options offering similar trip times
- Offers redundant means of propulsion with enhanced mission flexibility

**Technical and Developmental Risk**

- Reactor technology based on proven NERVA technology from early 1970's

**Safety**

- Safety issues primarily associated with NERVA Technology
- Minimum additional risk compared to NTP alone
- Additional complexity does result in some increased safety / reliability risk

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Figure 14