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NUCLEAR THERMAL PROPULSION PROGRAM OVERVIEW

Gary L. Bennett
NASA Program Manager
Propulsion, Power and Energy Division
Office of Aeronautics, Exploration and Technology
NASA Headquarters, Washington, DC

Picking up on what Larry Ross said, we are coming up almost on the first anniversary of the President's speech (Figure 1) committing us to finishing space station, going back to the moon and then going on to Mars, and he has repeated that on a number of occasions over the past year, and the money was put in the fiscal 1991 budget to work on the Space Exploration Initiative.

Specifically, the President requested $179.4 million for exploration technology, and of that, $11 million was earmarked for nuclear propulsion, subdivided into $10 million for nuclear thermal and $1 million for nuclear electric propulsion. There was flexibility put in that we could do studies on either concept under the 10 million.

And the President, again in the speech that he gave last July (Figure 2) spoke of finishing Space Station, going back to the Moon and then the mission to Mars; that's really the focus of our exploration technology program: the return to the Moon and then going to Mars.

In one of the meetings that I attended with Frank Martin, who was head of the Office of Exploration before it was merged with the old Office of Aeronautics and Space Technology, Frank said he did not necessarily need nuclear propulsion to go to the Moon but he certainly felt it was almost enabling to go to Mars.

The President in a number of speeches has talked about going to Mars within the lifetime of the scientists and engineers (Figure 3) who are going to be brought onboard to work the program and also to have people on Mars by the time of the 50th anniversary of the Apollo 11 landing which says that we have to be there by 2019. Now, in February (Figure 4) he approved policy for the Space Exploration Initiative and he said that is going to include both lunar and Mars elements as well as robotic missions. He said the near-term focus is going to be on technology development. And you may be aware that we have an Outreach Program, which General Tom Stafford is heading, and which is in response to the Vice-President's request that NASA cast a wide net looking for innovative ideas. There will be meetings and so forth coming up on that. In fact, NASA and the AIAA are sponsoring a meeting in the first full week of September to look at some of the technology items for the Space Exploration Initiative. There is going to be a focus on high leverage innovative technologies and certainly I think nuclear propulsion, both NTP and NEP, are part of that.

Now, it is probably going to take several years to come up with the mission architectures for how we go back to the moon and go on to Mars, and that requires us to maintain a certain amount of flexibility. I think in the nuclear propulsion program we have to be able to adapt to whatever comes out of these studies and we have got to be able to provide the planners with the information they will need.

NASA is going to be the principal implementing agency, but we are going to be working with the Defense Department and the Department of Energy. Certainly, when we get into nuclear propulsion we recognize the capabilities of the DOE laboratories, and we have been advertising the current workshops as joint NASA/DOD/DOE meetings. And I am glad to see the attendance from those agencies here.

Last November, the President approved our current version of the national space policy, which updated the policy that was in effect during the Reagan administration (Figure 5). One of the key points in that was that our goal is expanding human presence and activity beyond Earth orbit and out into the solar system. There is a background on this policy that's been developing over several years, dating back to 1986 when the Congressionally-mandated National Commission on Space issued its report on "Pioneering the Space Frontier" and in this report there is discussion of nuclear propulsion. And then Dr. Sally Ride issued a report to the NASA administrator in 1987 and that laid out about four mission scenarios including going to Mars. Of course, one of her recommendations was that NASA create an Office of Exploration, which NASA did, and that office issued the first of a series of annual reports in 1988, also looking at the Mars mission.

There are a number of reasons why we should go to Mars, (Figure 6) and certainly technology and education are key parts of it because we need something, at least in my view, that inspires people to go into science and engineering. My personal view is we have enough lawyers; we need people who are going to go out there and give us the technology edge because, as all the commentators are pointing out, the battle in the early 21st century is not going to be military, it is going to be economic. Certainly, continuing our journey into space and to Mars gives us the chance to understand planetary evolution. Perhaps the most fascinating thing concerns life on Mars, if it ever got a chance to start, and if not, why not. So again, that's our long-range goal and that's our focus on the nuclear propulsion program that we are developing.

Now, during the last year following the President's July 20th speech, NASA set up an in-house group which did the "90 day study," and that study looked at going to Mars and identified a number of key technologies (Figure 7) that are needed for human exploration of the moon and Mars and nuclear propulsion was one of those key technologies. So that was the first highlight on it.

Then in response to that, we put together within OAET, now the Office of Aeronautics

Exploration and Technology, an Exploration Technology Program which is to develop a broad set of technologies (Figure 8) to enable future decisions on development of future space exploration missions.

The Exploration Technology Program is not a sandbox, it is to be a critically needed focused technology program and it includes these technology areas. And again, one of them is nuclear propulsion. And the explorative technology program is the one that was budgeted at $179.4M in the President's submittal for FY91.

Now, specifically for nuclear propulsion these are the words that went into our internal budget documents (Figure 9). And we said that the technology that will be developed under nuclear propulsion is to address multiple approaches (Figure 10) for applying space nuclear power systems to the improvement of nuclear performance for human missions to Mars. We said we would start work on a nuclear thermal rocket propulsion technology and at the time we said solid core and gas core systems would be looked at. And later I will mention also liquid core concepts and all of these concepts were to be considered for future piloted missions to Mars. We also said we would be working on nuclear electric propulsion technologies and that would include both the reactor and the electric propulsion system.

For those of you who have followed this, we had a previous program called Pathfinder which is the precursor, if you will, for the Exploration Technology Program. We did have an element in the pathfinder program called Cargo Vehicle Propulsion which unfortunately was not funded. That was focused strictly on the electric propulsion thrusters. Now, under NEP, we have the reactor plus the electric thrusters and we also have nuclear thermal propulsion. So when we talk nuclear propulsion it consists of two key elements, and we have put together a draft thrust plan, as we call it, for all of nuclear propulsion and that is a draft document coming out of Headquarters.

We have set up various roles on this. Lewis Research Center here in Cleveland is our lead center within the NASA complex on working nuclear propulsion. And they are helping us pull this whole activity together. In nuclear thermal propulsion, they are being assisted very ably from the people from Marshall Space Flight Center in Huntsville, Alabama, and in nuclear electric propulsion they are being assisted by JPL, Jet Propulsion Laboratory, in Pasadena.

At this point I should thank a whole lot of you because you are going to see charts up here from the various NASA centers and DOE laboratories and contractors. Bob Frisbee at JPL frequently reminds me the difference between plagiarism and scholarship is whether or not you acknowledge the sources, so I want to acknowledge a lot of you on this. Now under nuclear thermal propulsion (Figure 11), we are going to be looking at the whole system, the reactor, shielding, pumps, and all of that.

Larry Ross mentioned, in his opening remarks, the previous work done at Lewis managing the NERVA program and other activities. I think that there is a synergism between chemical propulsion activities and nuclear propulsion activities, and this is a message I have gotten in talking to people at Lewis and Marshall. The ROVER/NERVA program in many ways led the country in the 1960s on cryogenic technology, but the chemical people with the Space Shuttle main engines and so forth have since gone beyond; there are things that we can learn from them.

One thing I would like to do is not get into a chemical versus nuclear mode; rather I would like to adopt a view that nuclear is simply an extension of chemical. We are going to take the chemical technology for pumps and nozzles and so forth and just heat the propellant in a different way.

Within our thrust plan, we have a number of goals (Figure 12). These include developing the technologies to apply space nuclear power to improve the performance for human missions to Mars. Our focus is really on the piloted missions, and out of this we want to come up with at least one concept that alone or in combination with other systems can meet the requirements for piloted and cargo missions to Mars.

Now, in combination it could be something like nuclear thermal propulsion plus nuclear electric propulsion, the hybrid concept. I think there is at least one talk on that scheduled during this workshop. It also might end up being chemical plus nuclear. There are various ways perhaps to do it. Our objectives (Figure 13) include developing safe advanced nuclear propulsion systems that are responsive to the Space Exploration Initiative requirements, and we have to have a focus on safety.

Right now NASA has a court case pending on the Ulysses mission, which is a European Space Agency spacecraft that NASA is launching this fall, and which has one radioisotope thermoelectric generator. We have been taken to court to stop that launch. We have also been asked to not allow Galileo to fly by the Earth in December, and we may get the judge's ruling this week. We have to be ever mindful of safety whenever we get into this nuclear arena. As the cliche goes we have to be squeaky clean. In fact, as one fellow said, if out of all of these workshops one piece of paper finds its way into the gutter and somebody comes by and picks it up, that piece of paper had better have the word safety on it.

We are going to look at component subsystems and systems technology, and what we want is to come out with a validated base for moving on in nuclear propulsion. There are project level goals (Figure 14 & 15) and Lewis has taken the lead and will be working with Marshall and JPL in coming up with project plans on nuclear thermal propulsion and nuclear electric propulsion.

Now, there is a bit of a strategy behind this I would like to spend a few minutes on. In putting all of this together, again our focus has been on safety, reliability and high performance technology. As to reliability, we are of course, aware of the problems on

Hubble and other things and so this is going to be a challenge for the people working the panel on advanced planning. How do we test a nuclear propulsion system? That's going to be something we are really going to have to wrestle with, and certainly there are strong arguments for all-up testing on the ground if we can do it.

We certainly need to work with the public, with Congress, and the administration on developing a consensus on the safe use of nuclear propulsion, because now we are doing something a little different from say a Galileo or Ulysses, where the device is just sent out. We are talking about sending people out a nuclear system and bringing them back into, perhaps, a low Earth orbit. And in fact, there is a meeting scheduled today in the Pentagon to wrestle with the question of the effects of gamma rays and other particle emissions from reactors on scientific satellites. Congress mandated that the Defense Department would provide a report on how reactors in space might affect science satellites such as the Gamma Ray Observatory and so forth. We are going to have to be sensitive to that with nuclear propulsion.

Out of our work we have got a chance to strengthen and extend the propulsion technology foundation for the civil space program. Again I want to emphasize we are just taking chemical another step further. A key part of this effort has to be involving the universities, because that's where the people are coming from who are going to carry these programs into the 21st century. Also, the program really needs to be done with other agencies such as the Department of Energy, the Department of Defense; their labs and their contractors have expertise that we don't have at NASA, and I think this maximizes the use of existing resources. And obviously, in this country, if you do something it really ends up being done by industry and by laboratories. So it's got to be done as a team approach involving industry and the universities and laboratories.

Again, to emphasize, this is to be a phased and focused technology development program. We have been asked throughout the Exploration Technology Program to set up "wickets" through which these various ideas have to flow and we are going to have to make decisions as we go along. We cannot continue to work nuclear propulsion or we cannot work our life support or artificial intelligence or whatever indefinitely. We have to be focused on where we are going with them.

The last issue is maintaining a flexible design approach. If you go back and look at the ROVER/NERVA program, it started out when the Air Force went to the Atomic Energy Commission looking for a way to have an ICBM, and they wanted a nuclear rocket ICBM. Then, when NASA was created, it became a vehicle for going to Mars. Next it became a tug to go from low Earth orbit to lunar orbit; so that's part of the reason you see a multiplicity of nuclear thermal propulsion designs in the late 1950s and 1960s. The requirements keep changing, so we have to be flexible; but as a colleague of mine once said, "we have to be flexible but not limp."

There are a couple of things on "why nuclear propulsion" that are coming out of studies that Lewis and Marshall and others have done. If you look at an all-propulsion chemical system, the initial mass requirement in the low earth orbit is pretty humongous (Figure 16). Once you go down into an aerobrake system or a nuclear thermal rocket either at 900 to a 1000 seconds Isp and even nuclear thermal rocket with aerobrake, they all significantly improved (Figure 17).

And I might mention that we have had some discussions on what we need to know and I will start by saying when nuclear is compared against chemical plus aerobrake, the aerobrake mass fraction used is quite often an optimistic assumption of 13 to 15 percent or something like that, so that needs to be noted. These have been the typical measures of performance, but there are people in Headquarters who have asked me a different question, not so much about the required mass in the low Earth orbit but about the trip time. In this particular study (Figure 18), for example, the electric propulsion systems were of the order of 650 days, although with some sort of a boost either from nuclear thermal or chemical they can get that down to a time comparable with nuclear thermal.

During the 90 day study there was a lot of interest in nuclear gas cores (Figure 19), simply because of short trip times, and there are people out there who believe that this is the major selling point for nuclear propulsion, getting people to Mars quickly so we don't have excessive life support issues to deal with, we don't have to extend the time during which the astronauts might be exposed to a solar flare, and we minimize the radiation dose they get from galactic cosmic rays.

This is another chart from Lewis showing plots of relative mass in the low Earth orbit as a function of engine thrust/weight (Figure 20). These have always surprised me, but the message that comes out of these is above about six to ten, thrust-to-weight isn't as important as specific impulse. So things to think about as you go into these deliberations on going to Mars are, short trip times and high specific impulses.

This is a chart that was presented at the NEP workshop (Figure 21). Perhaps there is a clue here that, if we are willing to relax our mass in the low Earth orbit, we can start pushing for shorter trip times, and perhaps nuclear will get there more quickly than chemical plus aerobrake.

As something that I want to leave you with, I will quickly mention that these nuclear propulsion systems certainly give us versatility (Figure 22). In the ROVER/NERVA program basic modules were developed, and they can be stacked up depending on what the mission is. Nuclear thermal propulsion and even nuclear electric propulsion offers the possibility of using in-situ propellants (Figure 23) and Bob Zubrin will be talking about that later.

In the days of NERVA, and more recently in other studies, people have looked at using the reactor not only for direct thermal propulsion (Figure 24), but also to drive a turbine alternator so you could have both power have a nuclear electric propulsion system as well.

The nuclear rocket program as set up in the 1950s and 1960s runs roughly like this (Figure 25). The point I want to make is that Los Alamos was turned on in about 1955 and the KIWI test started about four years later; this was before the National Environmental Policy Act and was a classified program. Also, Westinghouse and Aerojet were turned on around 1961, and again it was several years before we get into the NRX series.

It's now going to take several years to get a ground facility built up and running and tests going, so we need to be realistic about that. We may be a little optimistic in some of our sales pitches, but I think we ought to not kid ourselves about its taking time to do this.

This just simply shows the evolution of the Los Alamos concepts (Figure 26) and this was the Aerojet/Westinghouse NERVA (Figure 27) and I won't dwell too much on that. These (Figure 28) are various ways of running the engine and this breaks out the individual tests (Figure 29), ending up with the nuclear furnace.

Now, the NERVA/ROVER program had a price tag in 1960 dollars of $1.4 billion; if you mention those kind of numbers today people get a little nervous; but I have been told by several people that the cost of developing and qualifying the chemical engine on the advanced launch system is about $4 billion. The chemical people historically have thought of at least a billion dollars to qualify a chemical engine, so I don't think we need to apologize in the nuclear community that we might spend more than a billion dollars to develop something that is at least twice as good as what we have today. Nor should we be apologetic about the fact it may take several years to do it.

Even though the ROVER/NERVA program ended about 1972, some people have continued to work on it. Las Alamos and INEL looked at small advanced nuclear rocket engines (Figure 30) and low pressure engines and Brookhaven looked at particle bed reactor design (Figure 31), which improves heat transfer. And recently I was made aware of the fact that Brookhaven has looked at a liquid annular reactor system (Figure 32), about which they will talk later, which is a step toward the gas core system and allows even higher temperatures. Also, of course, work was done under the ROVER/NERVA program on gas core systems (Figure 33), wherein you could push the uranium plasma up to 10,000 degrees Kelvin.

Additionally, there was a nuclear light-bulb, and we will be hearing about this over the next few days. On paper, these advanced concepts certainly offer the possibility of quick trip times, because they have the right combination of thrust and Isp.

Now then, what we want to do, given the fact that there are these various concepts both under solid core and gas core and liquid core (Figure 34) is study them, get into more detailed designs, do some component testing, with the idea that somewhere toward the end of the decade we would come up with a basic nuclear thermal propulsion concept and similarly, a basic nuclear electric propulsion concept. So, basically, these workshops are put together as a way to educate those of us who are working on the nuclear thermal propulsion, and as a quick way to find out where all these concepts are. We do <u>not</u> intend to use the workshops to make any sort of selection, however.

Ideally, we would like to carry a number of concepts along in the planning, and for those of you who were involved in the ROVER/NERVA program, that program did more than just NERVA and Phoebus and so forth. It also worked on things like gas core and so forth. So it kept alive even more advanced technologies and I would hope that we would be able to continue to do that, and that we would not look at any one of these concepts as the be-all for the rest of the duration of humanity's existence.

There are a lot of issues that we have got to look at (Figure 35). Again, chief among them will be safety and safeguards plus quality assurance, how we test these concepts and what sort of reliability program we come up with. Obviously we are not going to be able to test dozens of these systems, so we have got to come up with a test program that will enable us to calculate the reliability and still come up with good reliability. These are the kinds of issues that we must address in our programs.

The scope that we will be working on (and liquid core should also be in here) (Figure 38), will be going through the different reactor types and how we move the heat around. Radiation shielding is going to be a key aspect. I might mention that under the Exploration Technology Program we have a separate program thrust that deals with shielding. That's being managed by our Materials and Structures Division.

Now, given the fact that back in January the President submitted this budget that included the $179.4 million for exploration technologies with $11 Million for nuclear propulsion, what are we going to do, given that we have no money in FY90?

Well, we kicked it around in several meetings (Figure 37 & 38) and decided that we should at least assemble what we can of the requirements. We will go out and talk to the people at MASE, the Mission Analysis and Systems Engineering group at the Johnson Space Center, and find out what assumptions they and the supporting centers have made about nuclear propulsion, what the requirements were on NERVA, and what the requirements were on SP100, because that's the current ongoing space nuclear system in this country. Particularly, we should learn where we are in safety, because the safety philosophy is different from NERVA to SP100.

In the days of SP100 and the SNAP-10A system, the idea was "burnup on reentry." People were looking at things as far-out of shooting cannons up the nozzle of NERVA to blow it apart to ensure that it would burn up on reentry; now we are looking at "intact reentry."

So we decided to pull together these workshops (Figure 39) and to assemble a data base on the various concepts; but we wanted to do more than just simply bring everybody in and go through the advocacy. We decided to put together a technology review panel, which will try to evaluate these things, separate the facts from the advocacy, and try to get the advocates evenly weighed and on a level playing field. Again there is no intention of making any decisions in terms of concepts, but rather to determine what work is needed on each concept to bring them up to enough design maturity that we can make intelligent decisions later on in the decade.

Next, we will work on our program and project plans. We have a draft program plan (Figure 40 & 41) called the Thrust Plan, and we are now working on draft project plans. Our goal is to get ready so that, depending on what money comes in in FY91, we can hit the deck running with strategy, and statements of work, and we would have our plans in place. We are going to do that by assembling the data bases and by holding these workshops; and I think a key part of the process is developing advocacy charts and papers.

Realize that we are going to have to sell this program and sell it and sell it; there are going to be reviews on top of reviews. Immediately after the 90 day study was completed the National Research Council (NRC) met and reviewed it, and we will have our own internal reviews, and our own Space Systems and Technology Advisory Committee (SSTAC). The National Research Council (NRC) has an Aeronautics and Space Engineering Board (ASEB) that will be reviewing it, and there will probably be Congressional reviews.

So these workshops will help us, through meeting you and seeing your charts, to put together a coherent total story on nuclear propulsion. We are going to use these workshops to put together that data base, to help us identify the technical issues and to help us define our program. Again, we are using the technology review panels to evaluate the data and they will be meeting with us again in September. Then we hope later in the fall to have a meeting with all of you give you feedback on where all of this is going.

Just to recap, our philosophy is developing nuclear propulsion technology for space missions and that means going into the critical subsystem and components. We are going to look at real system performance and operating characteristics, and we are going to look at specific space missions such as going to Mars. And we are going to have to have a program that's environmentally acceptable, that is certainly innovative, and that is driven by the mission requirements. It's going to be focused on critical propulsion components, including the reactor and the rest of it. We are certainly going to have to spend a lot of time wrestling with the philosophy on how we verify the system, and there are a number of requirements that are going to have to met, chief among them being safety.

I always like the quote attributed to Glenn Seaborg (Figure 42). He said what we are attempting to make is a flyable compact reactor, not much bigger than a desk, which would produce the power of Hoover Dam from a cold-start in a matter of minutes. So I always thought Seaborg had that pretty well in focus.

I think there is enough in this to keep us all busy, and again I remind everybody the 11th commandment of the nuclear community, we are not making decisions in these workshops, so "Thou Shalt Not Speak Ill of Another Nuclear Program." And with that, let's go to Mars.

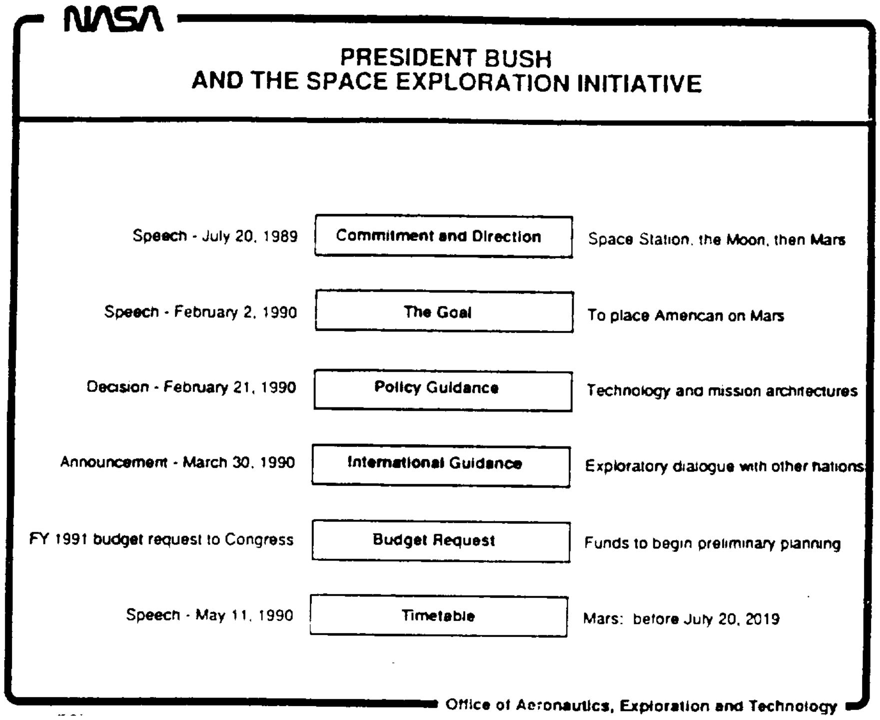


Figure 1

ORIGINAL PAGE IS
OF POOR QUALITY

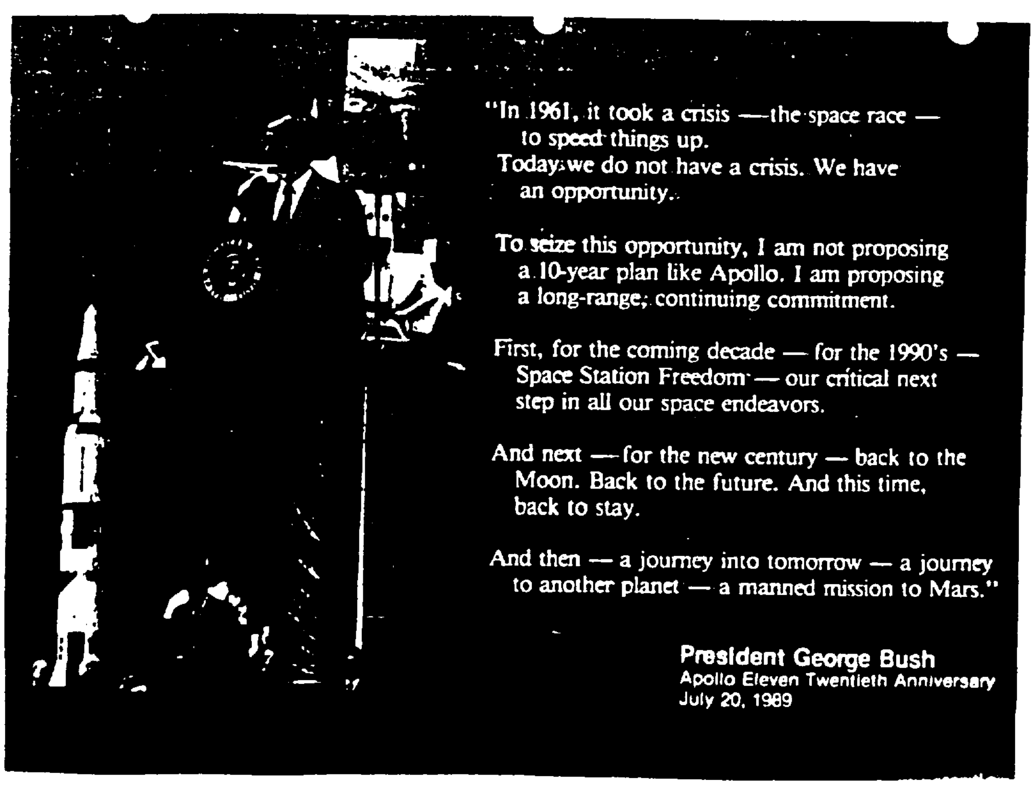


Figure 2

NASA

THE PRESIDENT STATES THE GOAL

"Our goal: To place Americans on Mars—and to do it within the working lifetimes of scientists and engineers who will be recruited for the effort today. And just as Jefferson sent Lewis and Clark to open the continent, our commitment to the Moon/Mars initiative will open the Universe. It's the opportunity of a lifetime—and offers a lifetime of opportunity."

President George Bush
Remarks at the University of Tennessee
February 2, 1990

Office of Aeronautics, Exploration and Technology

Figure 3

NASA

PRESIDENTIAL DECISION ON THE SPACE EXPLORATION INITIATIVE

On February 16, 1990 President Bush approved policy for the Space Exploration Initiative:

- Initiative will include both Lunar and Mars program elements, as well as robotic science missions
- Near-term focus will be on technology development
  - Search for new/innovative approaches and technology
  - Investment in high leverage innovative technologies with potential to make a major impact on cost, schedule, and/or performance
  - In parallel with mission, concept, and system analysis studies
- Selection of a baseline program architecture will occur after several years of defining two or more reference architectures while developing and demonstrating broad technologies
- NASA will be the principal implementing agency while DOD and DOE also will have major roles in technology development and concept definition. The National Space Council will coordinate the development of an implementation strategy by the three agencies

Office of Aeronautics, Exploration and Technology

Figure 4

NASA

NATIONAL SPACE POLICY – GOALS

On November 2, 1989, the President approved a national space policy that updates and reaffirms U.S. goals and activities in space.

- Strengthen the security of the United States
- Obtain scientific, technological, and economic benefits
- Encourage private sector investment
- Promote international cooperative activities
- Maintain freedom of space for all activities
- Expand human presence and activity beyond Earth orbit into the solar system

Figure 5

NASA

WHY ARE WE GOING TO MARS?

To fulfill the human imperative to explore

To understand planetary evolution

To enhance our understanding of life in the universe and find out if life once existed on Mars

To improve our country's technological competitiveness

To continue America's journey into space

Carry out the National Space Policy goal of expanding human presence and activity beyond Earth orbit into the solar system

Figure 6

TOP

KEY TECHNOLOGIES NEEDED FOR HUMAN EXPLORATION OF THE MOON AND MARS

- REGENERATIVE LIFE SUPPORT SYSTEMS
- AEROBRAKING
- ADVANCED CRYOGENIC HYDROGEN-OXYGEN ENGINES
- SURFACE NUCLEAR POWER SYSTEMS
- IN SITU RESOURCE UTILIZATION
- RADIATION PROTECTION
- NUCLEAR PROPULSION

Figure 7

NASA EXPLORATION TECHNOLOGY PROGRAM OAST

- The Exploration Technology Program is a program through which NASA will develop a broad set of technologies to enable future decisions on and development of future space exploration missions. The Exploration Technology Program is a critically-needed, focused technology program that will strengthen the technological foundation of the civil space program and the nation's leadership to go forward with ambitious future solar system exploration missions.

- The Exploration Technology Program is organized into eight technology areas:

Space Transporation	Lunar and Mars Science
In-Space Operations	Information Systems
Surface Operations	Automation
Human Support	Nuclear Propulsion

Figure 8

NASA EXPLORATION TECHNOLOGY PROGRAM OAST

NUCLEAR PROPULSION

The technology developed in the nuclear propulsion program area will address multiple approaches to applying space nuclear power systems to the improvement of mission performance for human missions to Mars

BASIS OF THE FY 1991 BUDGET ESTIMATE

Research will be started in nuclear thermal rocket propulsion technologies, including both solid core and gaseous core nuclear system concepts, capable of long-life and multiple starts, for future piloted mission to Mars applications, and in nuclear electric propulsion technologies, including both nuclear reactor systems technologies, advanced low-mass radiator and power management systems, and in high-power long-life electric thrusters for piloted missions to Mars.

Figure 9

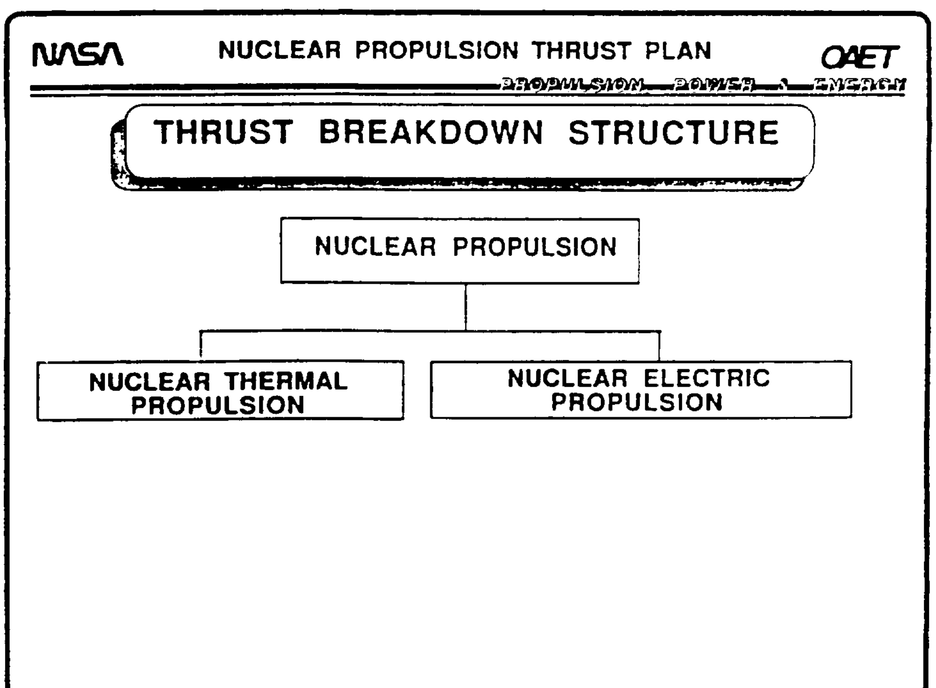
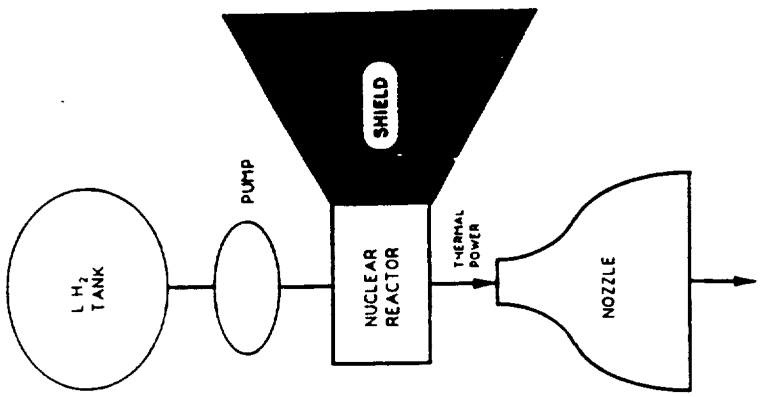


Figure 10



SCHEMATIC DIAGRAM OF A GENERALIZED NUCLEAR THERMAL PROPULSION SYSTEM

Figure 11

NASA NUCLEAR PROPULSION THRUST PLAN OAET

EXECUTIVE SUMMARY

THRUST GOALS

- **Develop the technologies required to apply space nuclear propulsion systems to improve the mission performance for human missions to Mars**
- **Identify and develop at least one space nuclear propulsion system that, alone or in combination with other propulsion systems meets the propulsion requirements for piloted and cargo missions to Mars (including unmanned precursor missions) and for which technical feasibility issues have been resolved**

Figure 12

NASA NUCLEAR PROPULSION THRUST PLAN OAET

PROPULSION, POWER & ENERGY

EXECUTIVE SUMMARY

OBJECTIVES

- Develop safe advanced nuclear propulsion system concepts that are responsive to SEI requirements (including vehicle/stage considerations)
- Demonstrate component, subsystem, and systems technologies for advanced nuclear propulsion systems
- Validate design analysis techniques and develop a technology base in the required disciplines

Figure 13

NASA NUCLEAR PROPULSION THRUST PLAN OAET

PROPULSION, POWER & ENERGY

EXECUTIVE SUMMARY

PROJECT-LEVEL GOALS

- Develop the nuclear thermal rocket propulsion technologies, capable of long-life and multiple starts, for future piloted and cargo missions to Mars, including unmanned precursor missions
- Develop the nuclear electric propulsion technologies, including nuclear reactor systems technologies, advanced low-mass radiator and power management systems, and high-power, long-life electric thrusters for piloted and cargo missions to Mars, including unmanned precursor missions

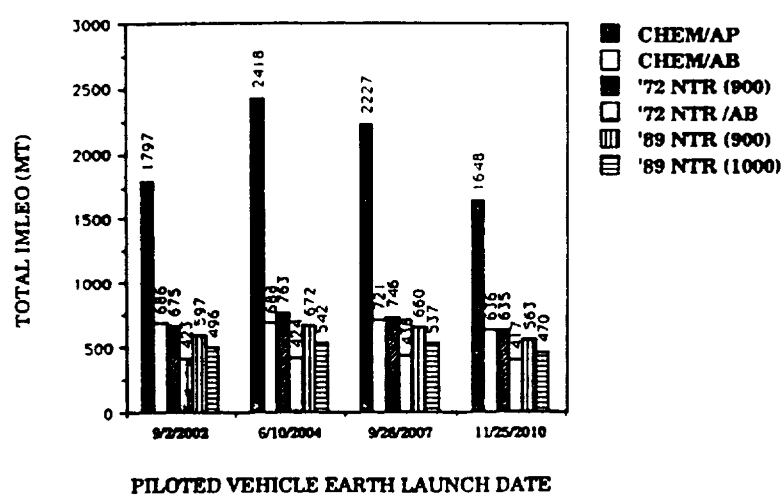
Figure 14

NASA **NUCLEAR PROPULSION THRUST PLAN** OAET

PROPULSION, POWER & ENERGY

- Develop safe, reliable, high-performance nuclear propulsion technology for exploration of the Solar System
- Develop a consensus on the safe use of nuclear propulsion in order to achieve public acceptance
- Strengthen and extend the propulsion technology foundation of the civil space program so that a new, higher technology plateau will be established for future propulsion programs
- Broaden participation of universities to enhance the scientific and technical educational level of the U. S.
- Coordinate with DOE, DoD and their labs and contractors to minimize duplication and maximize use of existing resources
- Implement through a joint NASA/DOE/DoD/Industry/University team approach
- Carry out a phased and focused technology development program with clearly defined technical objectives in order to identify early the best approach(es)
- Maintain a flexible design approach to accommodate changes

Figure 15



MARS EXPEDITION CASE - IMLEO SENSITIVITY TO LAUNCH OPPORTUNITY

Figure 16

IMLEO SENSITIVITY TO LAUNCH OPPORTUNITY
MARS EXPEDITION CASE

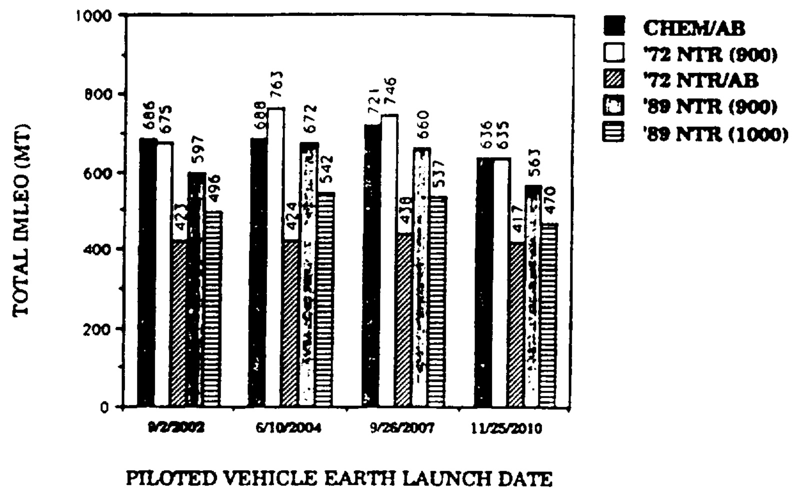


Figure 17

PROPULSION PERFORMANCE COMPARISON
NEP, SEP, AND SCR PILOTED MARS MISSION

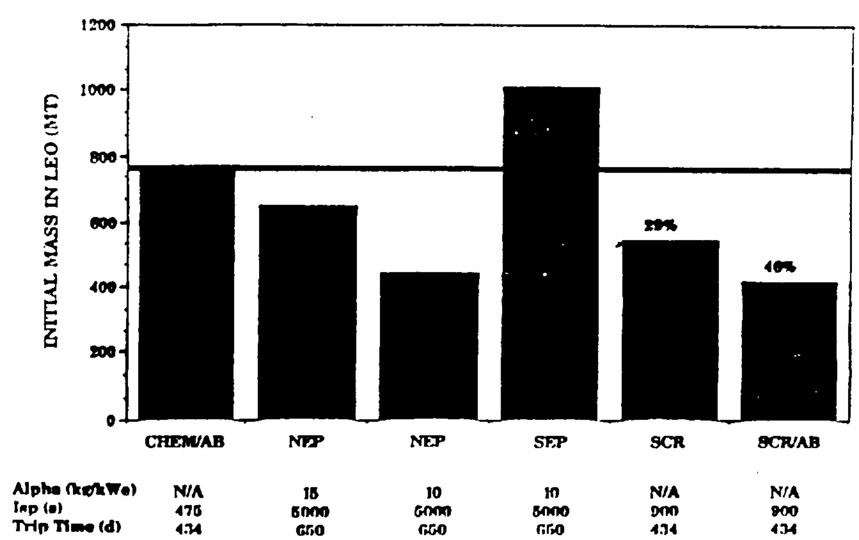


Figure 18

NASA

PROPULSION PERFORMANCE COMPARISON
SCR AND GCR PILOTED MARS MISSIONS, QUICK TRIPS

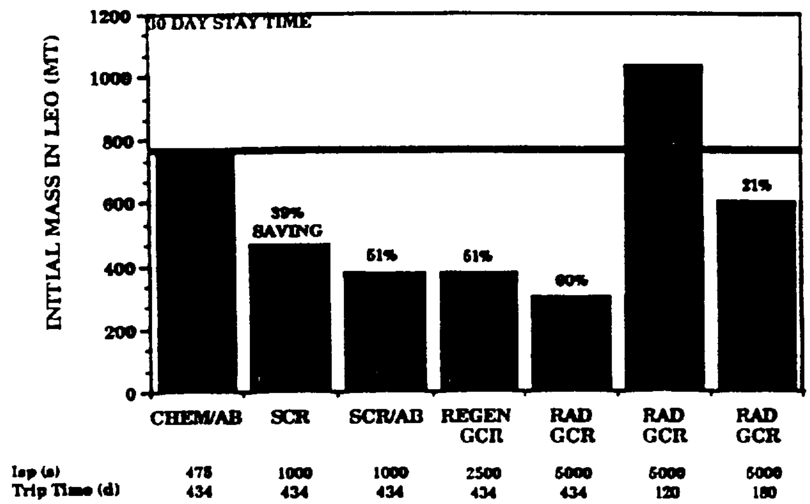


Figure 19

NTR MARS PERFORMANCE
THRUST/WEIGHT AND ISP VARIATIONS

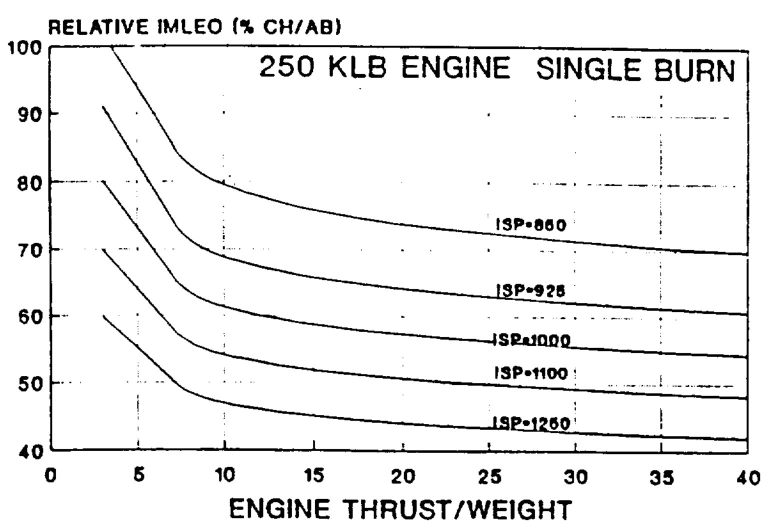


Figure 20

Various Opportunities For Given MTV Propulsion Options

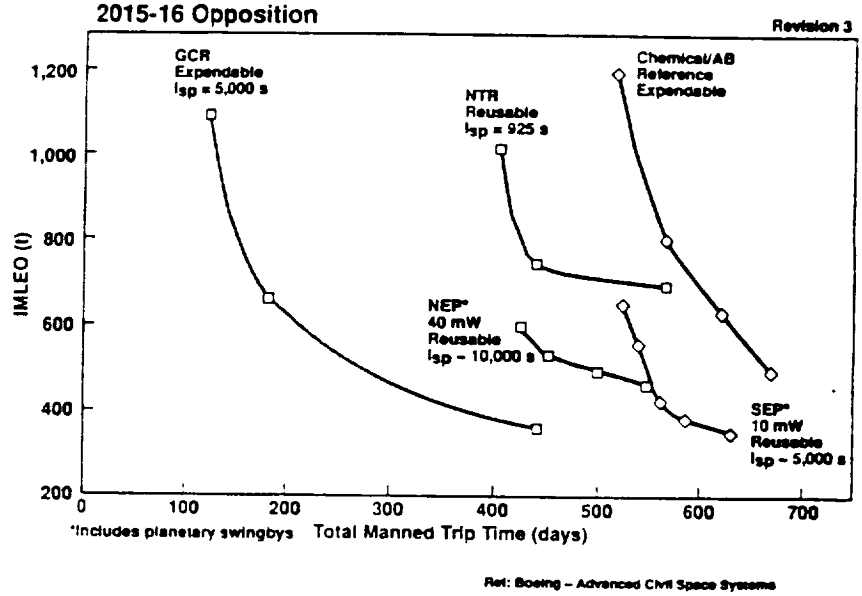


Figure 21

Versatility

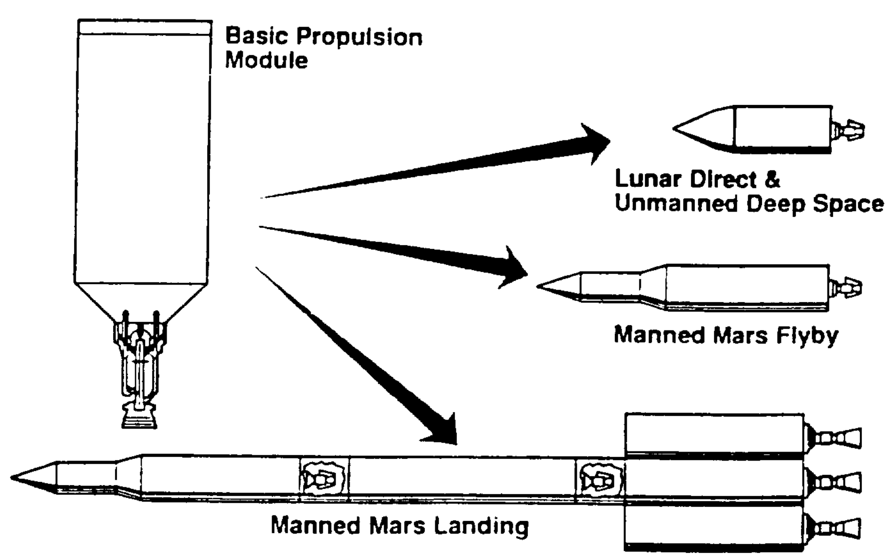


Figure 22

EXTRA-TERRESTRIAL PROPELLANT LANDER/HOPPER/ASCENT VEHICLE
(DIRECT FISSION-THERMAL PROPULSION)

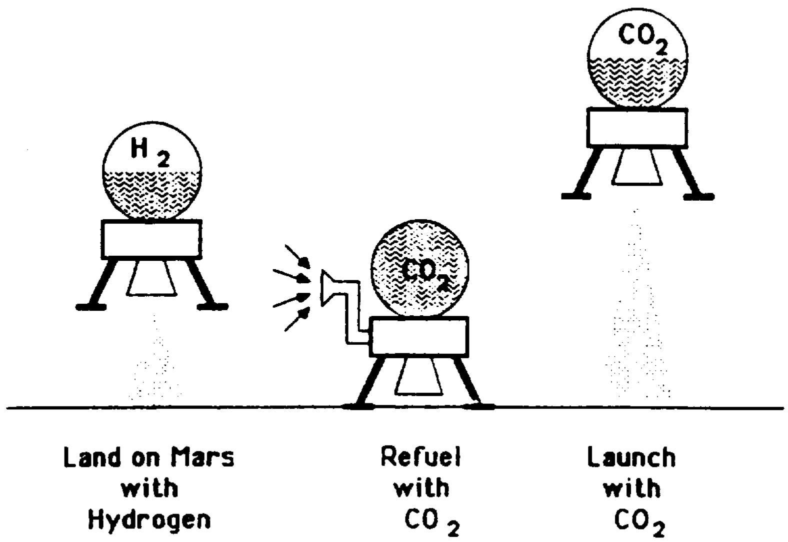


Figure 23

NERVA TECHNOLOGY HAS SYNERGISTIC APPLICATIONS

Steady-State Power

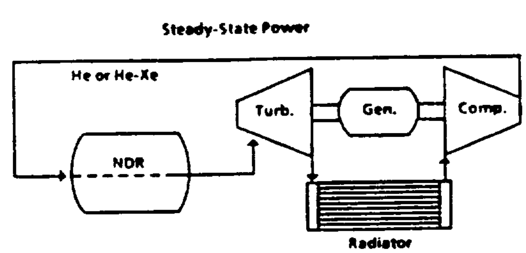
- 10's of MWe for electric propulsion

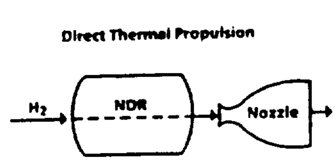
Direct thermal propulsion

- 15,000 to 250,000 pounds of thrust

Dual Power Systems

- High direct thrust (e.g., 75,000 pounds) plus low electric propulsion (e.g., 1MWe)





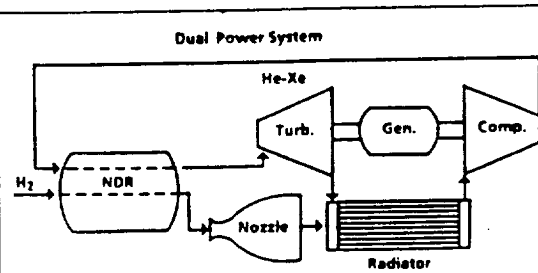


Figure 24

Nuclear Rocket Program

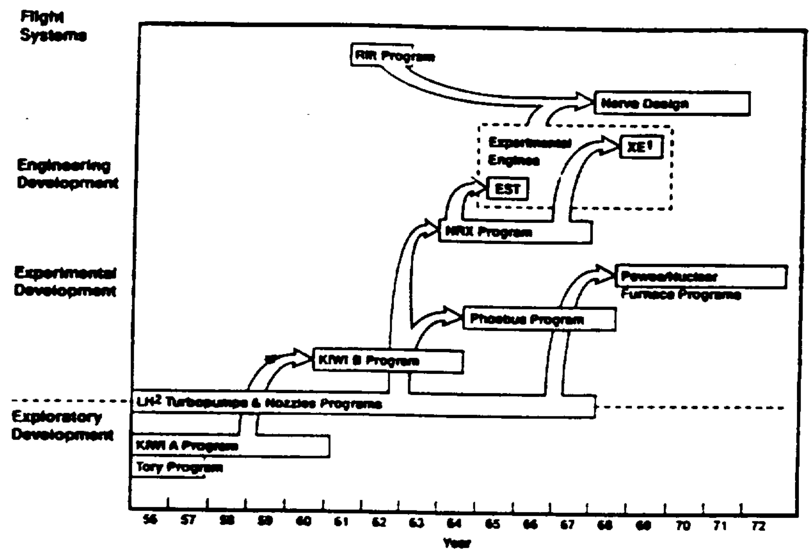


Figure 25

Evolution of Rover Reactors

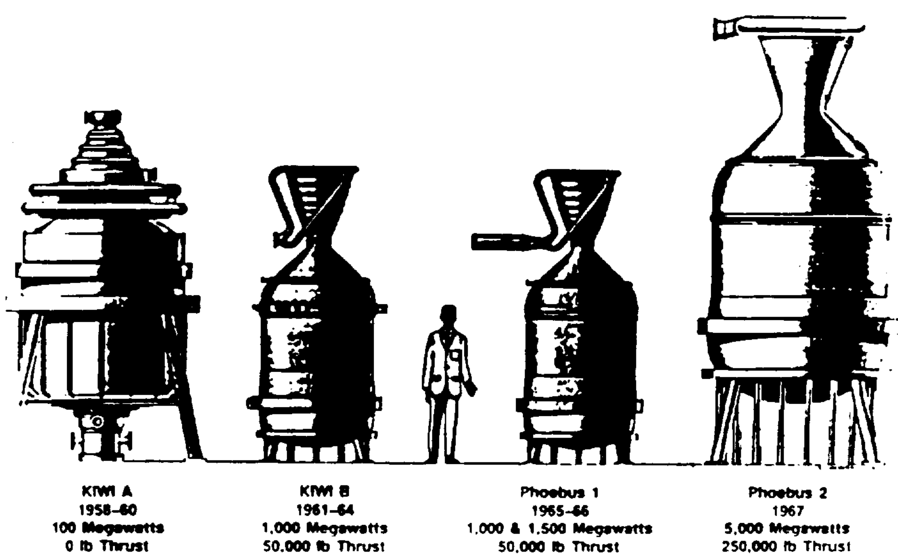


Figure 26

NERVA Flight Engine Configuration

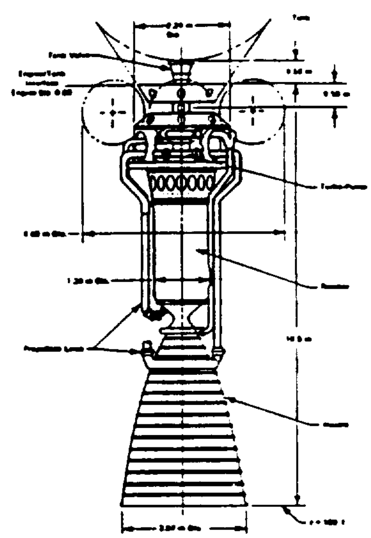
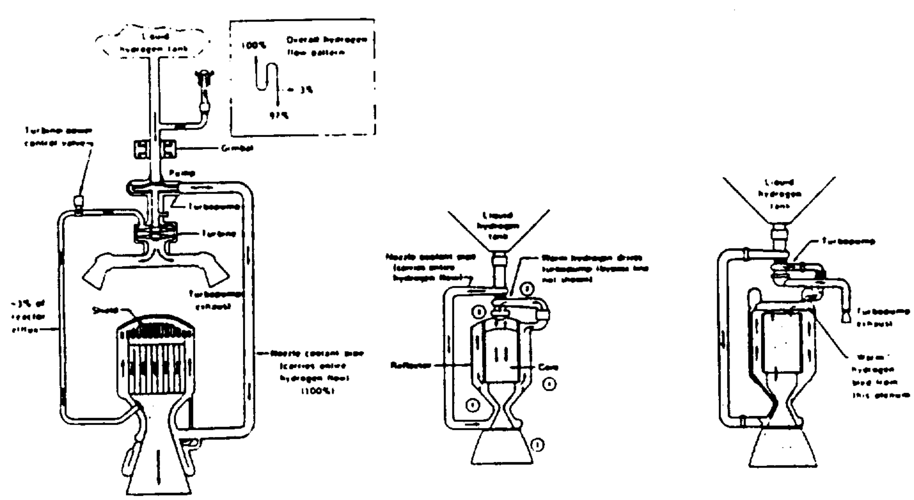


Figure 27

MODES OF NUCLEAR ENGINE OPERATION



Hot Bleed Cycle   Full-Flow Cycle   Cold Bleed Cycle

Figure 28

NERVA/Rover Reactor System Test Sequence

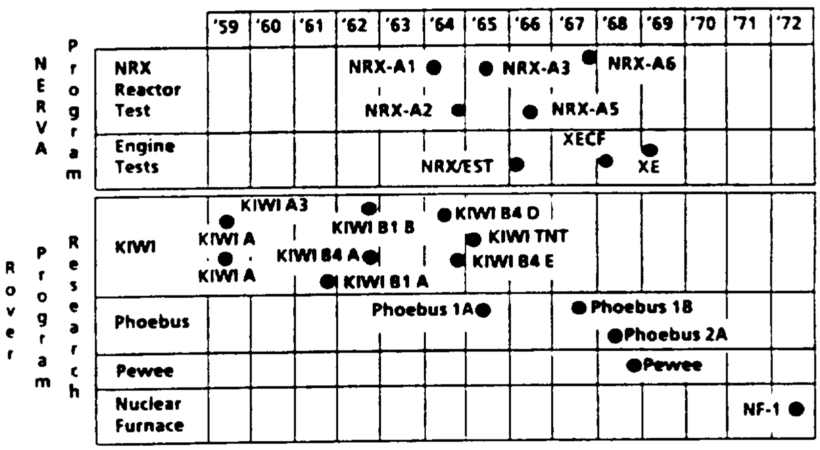


Figure 29

SMALL/ADVANCED
NUCLEAR ROCKET ENGINE
(SNRE/ANRE - LANL/INEL)

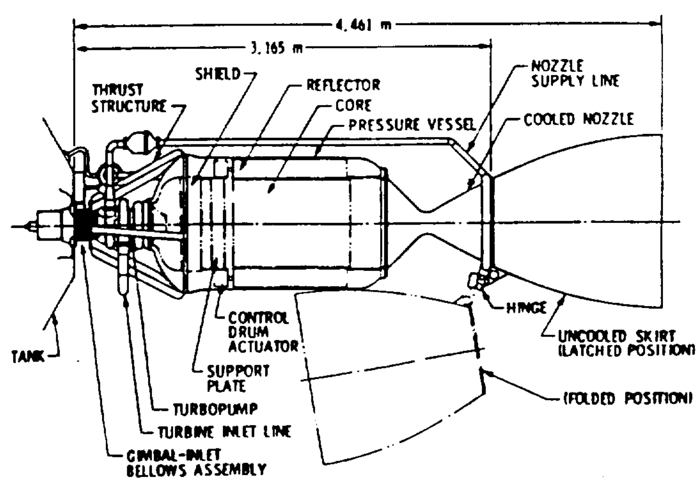


Figure 30

PARTICLE BED REACTOR DESIGN

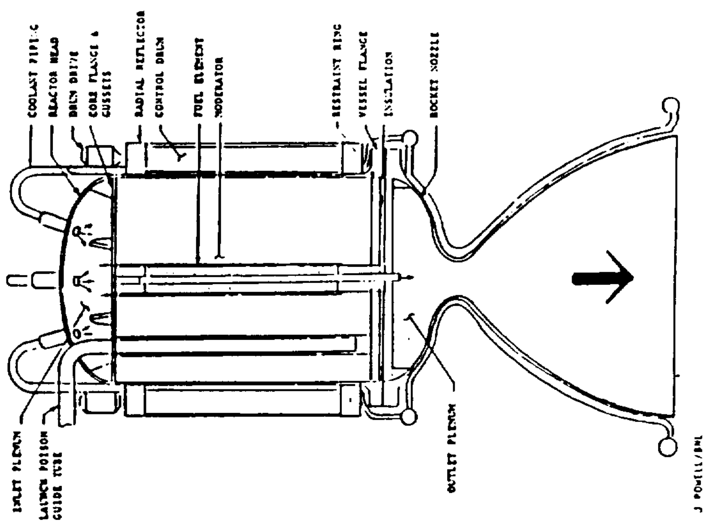


Figure 31

LIQUID ANNULAR REACTOR SYSTEM

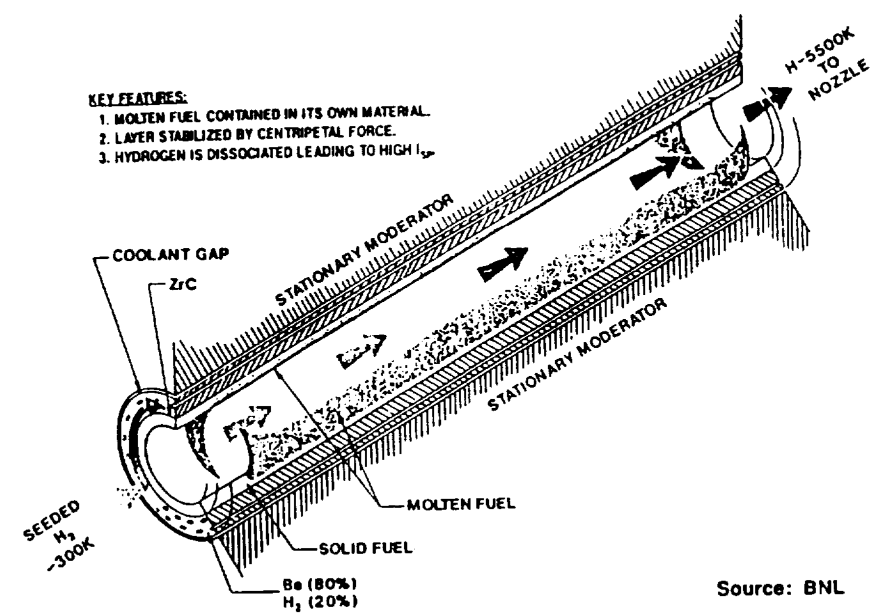


Figure 32

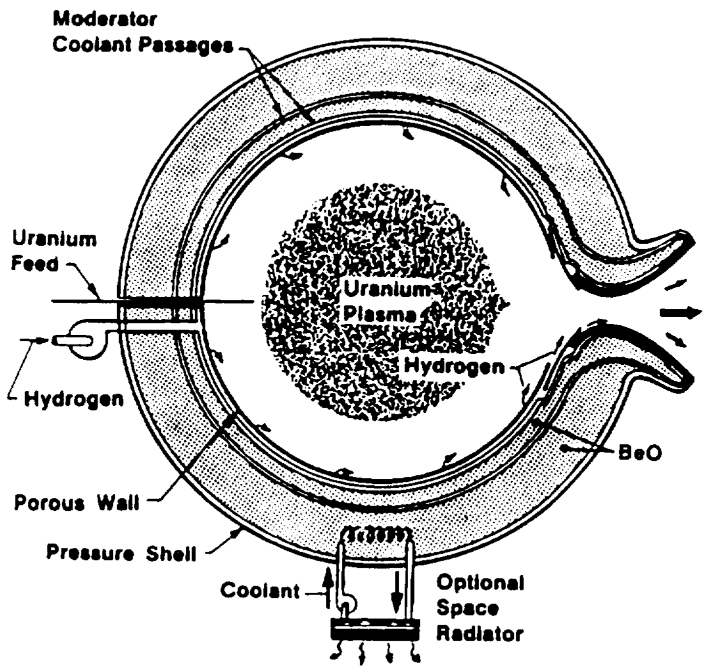


Figure 33

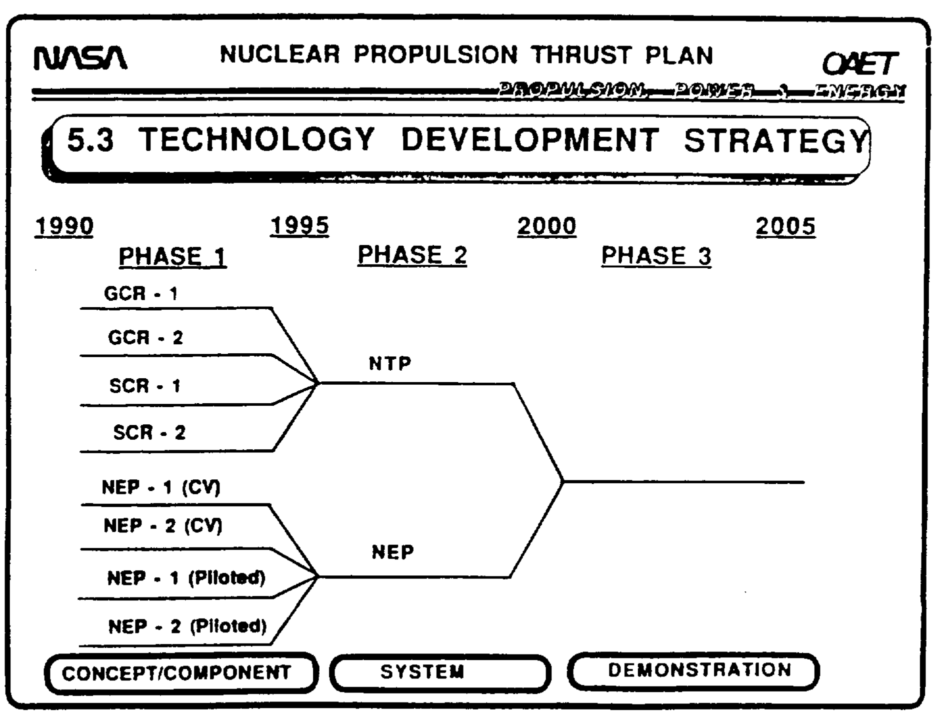


Figure 34

NASA NUCLEAR PROPULSION THRUST PLAN OAET

PROPULSION, POWER & ENERGY

EXECUTIVE SUMMARY

KEY TECHNICAL ISSUES

Safety/safeguards/QA (during all program phases)
Qualification/acceptance test strat.
Reliability and fault tolerance
High Performance engines (including reactors)
Reusability/restart capability
Reactor Fuel
Structural Aspects
Turbomachinery
Vessels/Nozzles
Pumps/Valves
Diagnostic Capability
Control Systems (neutronics/ I&C)

Power Processing Units (NEP)
Thrusters (NEP)
Space operations
- radiation shielding
- design criteria for in-space operation and maintenance

Propellants/Prop. handling
Thermal hydraulics
Thermal Management
Materials
Lifetime
Mass/Volume Limitations
In-situ Prop. Utilization

Figure 35

NASA NUCLEAR PROPULSION THRUST PLAN OAET

PROPULSION, POWER & ENERGY

4.2 CONCEPT DEVELOPMENT SCOPE

GAS CORE ROCKETS

Reactor type
Heat transport and rejection
Safety Systems
Radiation Shielding
Control
Pressure vessel
Turbopumps
Nozzle
Thrust Structure

SOLID CORE ROCKETS

Reactor type
Heat transport and rejection
Safety systems
Radiation shielding
Control
Pressure vessel
Turbopumps
Nozzle
Thrust structure

NEP

Reactor type
Heat transport and rejection
Power conversion unit
Safety systems
Radiation shielding
Control
Pressure vessel
Turbopumps
Power processing unit (PPU)
Thrusters
Thrust structure

Figure 36

NASA EXPLORATION TECHNOLOGY PROGRAM OAST

NUCLEAR PROPULSION

WHAT NEEDS TO BE DONE IN FY 1990

- ASSEMBLE "REQUIREMENTS"
  - Mission Study Assumptions (workshop)
  - NERVA Requirements
  - SP-100 Requirements (especially safety)
- ASSEMBLE DATA BASE ON CONCEPTS
  - Workshops on GCR, SCR and NEP
  - Publish report (data base)
- DEVELOP PROGRAM AND PROJECT PLANS
  - Prepare SOW for Contracts
  - Prepare procurement packages

Figure 37

NASA NUCLEAR PROPULSION OAET

FY 1990 PROGRAM STRATEGY

Objective: Develop the FY 1991 program, including
- procurement strategy
- statements of work
- thrust/project plans

Implementation: Assemble data base

Hold Workshop(s)

Figure 38

NASA **NUCLEAR PROPULSION** OAET

NUCLEAR PROPULSION WORKSHOP

Objectives

- Assemble data base
- Identify technical issues
- Provide input for FY 1991 studies

Approach

- Hold workshop covering
  - Mission studies
  - Safety
  - GCR/SCR/NEP
- Collect data and have technical "tiger team" evaluate data
- Issue evaluated data report and workshop summary

Figure 39

NASA **Nuclear Propulsion Thrust** OAET

NUCLEAR PROPULSION PROGRAM PHILOSOPHY

Objective:

- The development of nuclear propulsion system technology for space missions
- The development of critical subsystem and component technology
- Evaluation of real system performance and operating characteristics
- The evolution of a propulsion system concept that will meet the objectives of specific space missions when firm objectives are identified
- The development of a sound technical system verification approach which is environmentally and programmatically acceptable
- Pursuit of innovative and advanced technologies with significant mission advantages

IN SUMMARY, A MISSION/REQUIREMENTS DRIVEN TECHNOLOGY PROGRAM IS PLANNED

Figure 40

NASA Nuclear Propulsion Thrust OAET

PROPULSION, POWER AND ENERGY

NUCLEAR PROPULSION DEVELOPMENT PHILOSOPHY

Principal thrust directed to the development of critical propulsion components and subsystems that significantly affect propulsion system characteristics:

- Reactor subsystem
- Thrusters (for NEP)
- Nozzle (for NTP)
- Turbopump assembly (for NTP)
- Thrust vector control system (for NTP)
- Power system (for NTP)
- Power processor (for NEP)
- Control system

Development of a verification approach that includes components, subsystems and systems, and addresses:

- Analysis
- Simulation
- Test

Requirements priority in order:

- High reliability and ground/flight safety
- Development cost/risk
- Performance/Weight
- Remote maintenance (robotics)

Figure 41

What we are attempting to make is a flyable compact reactor, not much bigger than an office desk, that will produce the power of Hoover Dam from a cold start in a matter of minutes

– Dr. Glenn T. Seaborg
Chairman
Atomic Energy Commission

Figure 42