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Near Earth Object Fuels (neo-fuels): Discovery, Prospecting and Use

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Abstract

The 1992 discovery of a water-ice, near-Earth object (NEO) in the space near Earth is evaluated as a source of rocket fuel and life support materials for Earth orbit use. Nuclear thermal rockets using steam propellant are evaluated and suggested. The space geological formation containing such water-rich NEO's is described. An architecture couples near-Earth object fuels (neo-fuel) extraction with use in Earth orbits. Preliminary mass payback analyses show that space tanker systems fueled from space can return in excess of 100 times their launched mass from the NEO, per trip. Preliminary cost estimates indicate neo-fuel costs at Earth orbit can be 3 orders of magnitude below today's cost. A suggested resource verification plan is presented.

Introduction

Issue: High Cost To Access Space

Extremely high cost handicaps our ability to use the space near Earth for remote sensing, surveillance, navigation and communications, and prevents us from occupying and industrializing space. The root cause is that we must launch from Earth everything we will ever need in space, especially the propellants and fuels to change our orbits and to rapidly position our satellites. The launch costs are so high because the rocket fuel mass required to launch a given payload is so large.

What developments would change this? We need a source of rocket propellants (fuels) in space that we can easily extract. And we need a very simple way to use the fuels. The discovery this year of neo-fuels might have the potential to completely change the way we access space. To determine if neo-fuel even qualifies we need to answer a few basic questions, such as:

- What is the extent of the discovery?
- Do the objects contain water, as claimed?
- Is the water on them accessible? Or is it too deep or too difficult to extract?
- Are there many of them, or are we dependent on just one?
- Is there more than just rocket fuel on them?
- Do they have the basic resources to feed plants and make space habitable?
- Can we bring back the water to orbits about Earth?
- Can we use the water in simple steam rockets for propulsion?
- Do nuclear thermal rockets or space nuclear power systems enable the use of these materials?
- Can we use solar power?
- Can the costs be lower than launching the same materials into space from Earth?
- How much lower? Under what conditions?
- Can the water lower the cost for manned missions to Mars?
- Could we keep our current schedule to go to Mars, but at a much lower cost?
- Could we take many more people for the same cost?
- Is the discovery big enough to initiate the exodus of people into space?
- Or is it just an interesting discovery of somewhat useful space materials?
- What should we do next? Should we begin a gigantic program now?
- Or should we begin the smallest possible prospecting and assay program to verify the value of the newly discovered resources?
- What is conservative plan to investigate the most likely good candidate objects?

Can this discovery can change the way we access space?

Discoveries

Active Comet & Enabling Propulsion

Two discoveries came to fruition this year. Astronomers discovered a rocket propellant/fuel object in the space near Earth. And engineers discovered a simple means to bring the materials back to Earth orbits.

Fuel/Propellant Resources In Space

An active comet has been discovered in the swarm of asteroidal NEO's, whose orbits cross or come close to that of Earth. Wetherill (1991) predicted that the final meta-stable solar orbit for comets is a swarm centered just past Mars (2.2 AU) and on the orbital plane of the Earth, and with perihelia that come closer to the Sun than Earth. This formation happens to be indistinguishable from the observed swarm of NEO's, which orbit the Sun between the orbit of Mercury and somewhere past Mars. Figure 1 shows this swarm, courtesy of Sykes. The object "1979 VA" was an object in that formation and was thought to be a carbonaceous, soft rock containing ~10% water as hydrated mineral. On 14 Aug 1992 Bowell (1992) reported through the Central Bureau for Astronomical Telegrams that this object was in fact an active comet, as predicted. Wilson and Harrington observed its "tail" in 1949. Figure 2 shows a segment of this 1949 survey plate, courtesy

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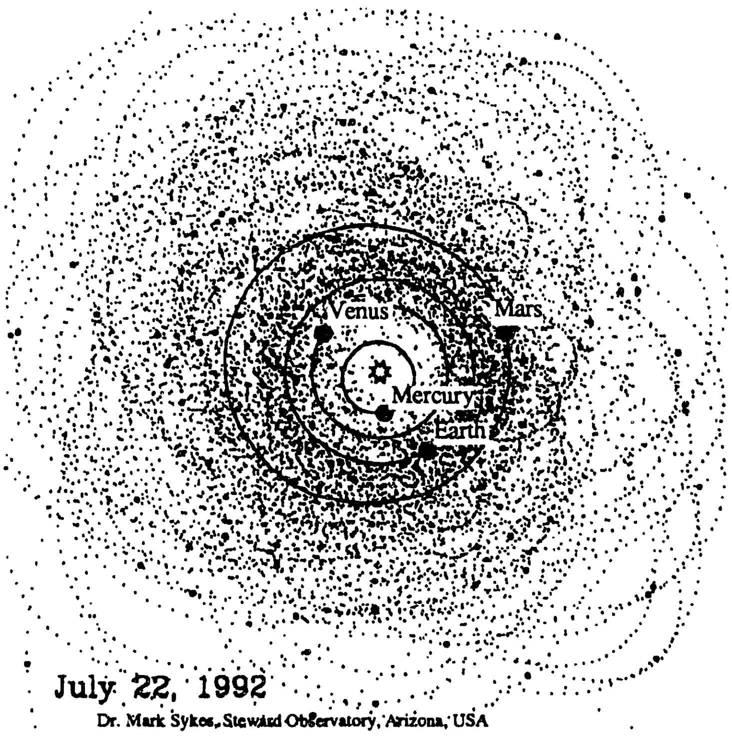


Figure 1 The objects and orbits of the 208 known NEO's as of 22 July 1992 show a swarm engulfing the space near Earth's orbit. The chance of encountering a NEO is proportional to the density of dots in a region. Half of the objects are expected to contain water in some form. Some fraction are expected to be comet remnants. One is known to be a comet: (4015) 1979 VA = Wilson Harrington.

Shoemaker. They did not have enough observations in 1949 to give a good orbit. The observations of 1979 VA, numbered object (4015), provided the precise orbit required to be able to look back into the photographic plates of astronomical history to see if the object was ever observed in the past. It was, as a comet.

Resources

Sensors passing through the comet tail and other direct, satellite measurements of the comet Halley indicated that comet interiors contain permafrost or frozen mud at -50 Celsius. Figure 3 shows comets are covered by a layer between 10 cm and 10 m thick of dirt and/or extremely dark carbonaceous sooty material. The composition is approximately ~50% water ice, ~10% CO and CO_2, and ~0.5% of a conglomerate of Carbon, Hydrogen, Oxygen and Nitrogen (CHON) materials. See Huebner (1990), Fanale (1991) and Lebofsky (1991). These are the raw materials to make rocket propellant, construction materials and plant food, and are crucial to sustaining life in space.

Low Gravity Essential

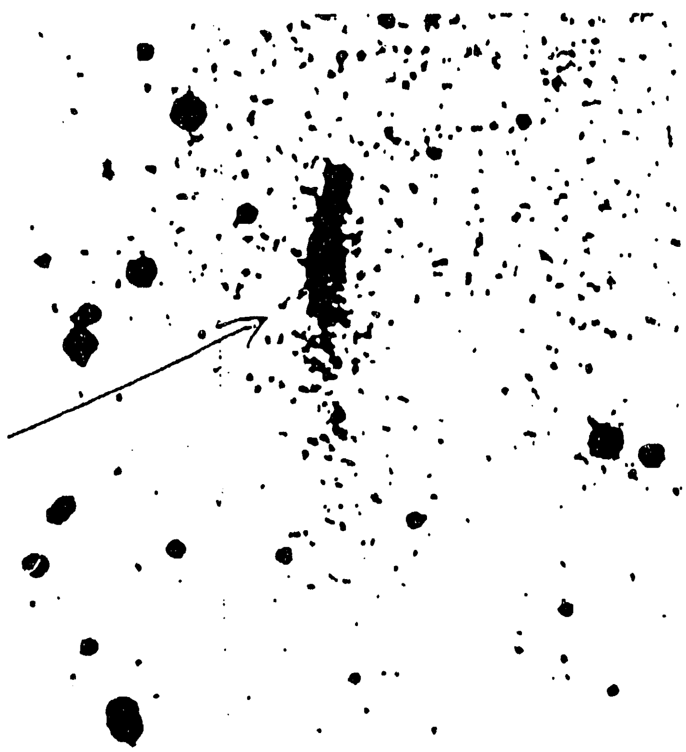
We can mine the entire NEO because it has negligible gravity. For example, the difficulty of lifting mass from a 1000 meter deep pit is 10,000 times easier than on Earth. Similarly, a small, 1 ton thrust rocket would launch 10,000 tons away from the comet.

Heat Melts Frozen Mud

We would extract the water by heating the frozen mud to just above boiling. In the vacuum of space this temperature is about 1 Celsius. Then we would separate the dirt and stones from the vapor, for example, by using a 1 meter diameter vortex flow chamber (see Stone, 1975). We would condense the cold steam to get pure water.

How much energy would it take to do this? A small nuclear reactor with about 1% of the power of the reactor in a nuclear submarine could melt melt nearly 19,000 tons of water per year. A 2 Megawatt thermal heat source would provide the 2.2 MJ / kg to melt the frozen mud to 1 Celsius vapor at near water triple point conditions if it operates on a 5800 hour per year schedule.

One might note that a Titan IV launch could send such a 2 Megawatt thermal, 200 Kilowatt electric system to nearly anywhere this side of



Survey Plate courtesy G. Shoemaker 21Aug92
first sighting in 1949, by Wilson & Harrington

Figure 2 Comet (4015) 1979 VA = Wilson Harrington, shown here with a tail in a 1949 plate, is about 5 km across and may have about 100 Billion (1E11) metric tons of water ice. It's gravity is very low and about 1/10,000 that of Earth, which is crucial for it to be useful to us. Its orbit perihelion is 1.003 AU (Earth is 1.00000) and has a 4.296 year period.

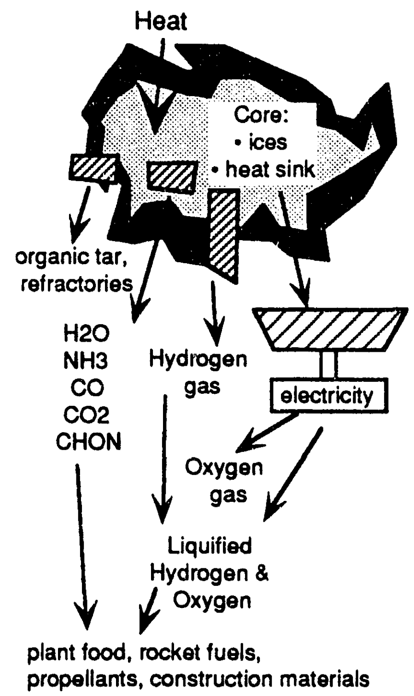


Figure 3 Heat liberates or converts comet raw materials into rocket fuels and propellants, plant food and construction materials.

Jupiter.

Electricity Provides Fuels

Electrolysis separates water into hydrogen and oxygen gases. Compressors and coolers condense the gases into cryogenic liquid rocket fuels.

How much energy does it take to separate the water into fuel and condense it? How heavy are the required systems? The International Space University "International Asteroid Mission" study (ISU 1990) sketched just such a system and provided a credible point design to estimate the weight and energy needed. Their distillation device uses 0.8 MW to purify the water. Their electrolysis and radiator system uses 3.2 MW to separate the water. A liquefier and radiator consumes 1.2 MW electric to liquefy Hydrogen, and 0.6 MWe runs the Oxygen liquefier. This would produce 76 kg/hr cryogenic Liquid Hydrogen and 610 kg/hr Liquid Oxygen. Operating for 5400 hrs / yr their system would produce 3.7 kilotons per year and consume 5.8 Megawatts electric. Their 200 ton system would process a few thousand tons per year, or 0.63 kilotons per year per Megawatt electric.

Ice = Heat Sink

A compressor to liquefy the gasses can use the cold, -50C temperature of the comet permafrost as a heat sink in place of very heavy radiators. Space is a thermos jar. This means a heavy radiator is required to radiate waste heat to space. On Earth the air or water simply convects or conducts it away, using heat exchangers weighing orders of magnitude less than their space counterpart. The cold ice would provide just such a conductive heat sink.

Heat & Comet Mass Produce Hydrogen

The gas shift reaction uses 1100 C heat, water and carbon to yield gaseous hydrogen and carbon monoxide or carbon dioxide. This produces hydrogen without electricity. Electricity is very expensive to produce in space. A nuclear reactor is a very compact thermal heat source. And hydrogen is an ideal nuclear thermal rocket (NTR) propellant.

Simple Electric Production

A simple but inefficient use of the water ice resource would produce electricity using an "open cycle" system. A steam turbine operating at 500 Celsius would exhaust directly to the vacuum of space or to a -50 Celsius ice pile. This would allow compact, multi-ton turbine systems to produce hundreds of Megawatts of shaft horsepower. This would allow relatively low mass systems to generate hundreds of Megawatts of electricity.

This process would waste resource and so would probably only be used in severe circumstances. For example, if the comet were on a collision course with Earth, then nudging the entire body off course as fast as possible might warrant inefficient use of its contents.

Architecture for use

Figure 4 shows how a system to obtain and use neo-fuel would resemble terrestrial systems to extract and deliver oil. The equivalent of a drill rig would extract and purify water at the comet. A space tanker would take on the water payload and use some of the water in its own rockets to nudge the tanker to into a barely captured Earth orbit. At Earth orbit it would transfer the water to a holding tank in space and go back for more. The holding tank orbit would be controlled so that it slowly decays to an orbit closer to Low Earth Orbit (LEO). There, a fuel processing and dispensing facility would service gas stations.

At LEO users would buy the fuel and use it to take communication and weather satellite vehicles to Geosynchronous Earth Orbit (GEO), navigation satellites to a Medium Earth Orbit (MEO), and for other, defense system uses. This would provide a market to make profit.

Once the infrastructure is in place, the cost of space fuels is estimated to be low enough to transport minerals and metals to Earth itself from close-by NEO's.

Several options to use the comet mass (neo-mass) include using the water itself as "fuel." Doing so would use about twice as much water over what would be used if the water were converted to liquid hydrogen and oxygen. But if water is cheap enough then simplicity may dominate. One could use solar heated steam rockets. This would permit us to keep the nuclear systems in deep space and

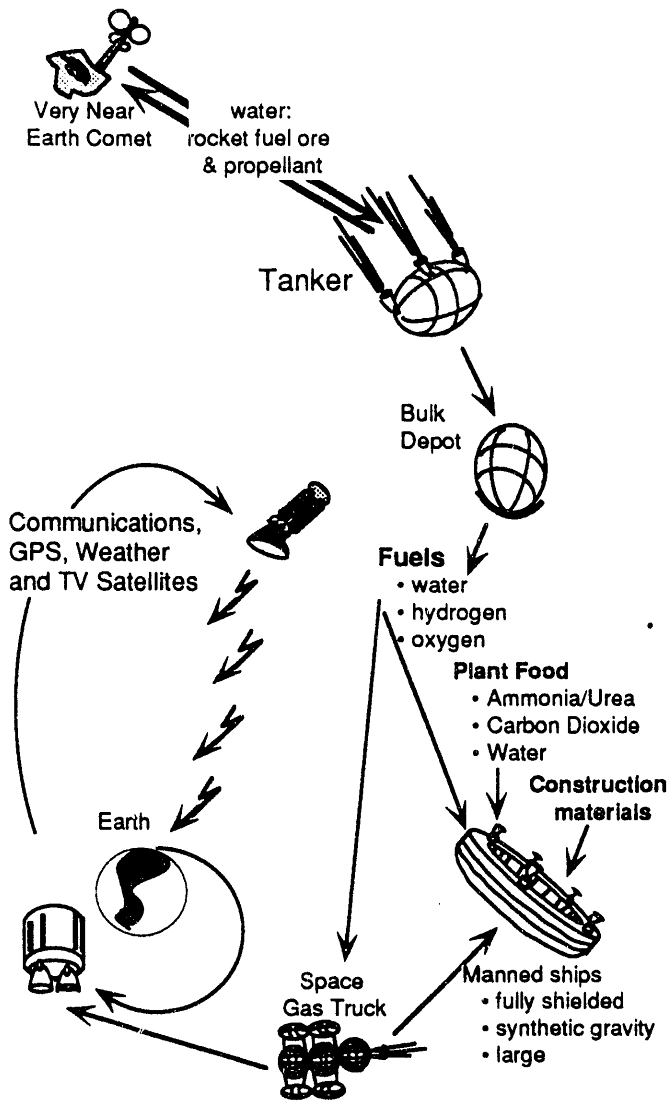


Figure 4 Extracting and using comet fuels, propellants and materials in space is similar to oil extraction and delivery on Earth. The fuels are extracted at the comet and transported in bulk by a space tanker that uses some of its payload as fuel. At Earth orbit a large processing and dispensing facility services gas stations. Users of the fuels would send commercial communication, weather, news and navigation satellites to high orbit. It takes 3 pounds of fuel at low Earth orbit to send a each pound of satellite to its operational orbit.

only use solar power near Earth.

An incidental use would be to industrialize space. Manned missions would become affordable.

The key question applying to all the above uses is the cost. This will be addressed later.

Many Fuel Objects In Formation

How many fuel objects are close to us? How close are they? What ΔV must a rocket achieve to cause a payload capture into an Earth orbit? What ΔV is required to prospect for and assay these objects? Figure 5 gives an estimate of the ΔV distance of the best known resource candidates. Shoemaker (1978) provided the closed form ΔV estimate for perfectly phased orbital transfers between the elliptic orbit of a NEO and a circular orbit of the Earth. This is the least ΔV that would ever be required. In practice, the ΔV will always be higher than the stated value. Fortunately, objects in elliptic orbits spend most of their time near aphelion, allowing orbital phasing maneuvers to be achieved without too much excess ΔV. A quick statistical evaluation evaluation using Friedlander (1990) data suggests that a 15% to 30% increase in V_∞ can be expected.

The table includes a 50% margin at Earth capture to provide the required excess ΔV. The table also shows the closest and farthest distance from the Sun, the orbit inclination, the relative velocity of a tanker vehicle coming to Earth from the object (V_∞) and the rendezvous velocity at the comet.

The three useful kinds of NEO are 1. known comets, 2. spent comets, and 3. low temperature hydrated clays. The remainder of the NEO's are minerals, metals and other possibly useful rocks.

Comet object (4015) 1979 VA = Wilson Harrington, (VA) is close in the sense that it has a capture ΔV of about 4.6 km/s. Almost all of this lies in the relative velocity between VA and Earth, labeled in the table as "Earth capture V_∞." The object spends most of its time near its aphelion of 4.3 AU. Its orbit is inclined by about 2.8 degrees and has a 4.3 year period.

The NEO Oljato shows strong evidence for water sublimation. Russel and Arghavani (1930-1990) shows that each time Oljato passes by Venus it disrupts the magnetic field associated with the solar wind. The explanation most fitting the data is that the solar UV ionizes the water vapor subliming away from Oljato. McFadden (1991) has observed a UV burst just after Oljato perihelion, also indicating a water vapor tail. The Indian name "Oljato" means "moonlight water," perhaps suggesting Native American s observed a tail at some time in history.

Ostro (1992) reports that Adonis has a radar spectrum like that of Calisto, the large water moon of Jupiter.

A'Hearn (1992) reports the possibility of water frost forming on the asteroid Ceres during its spring time.

There are about 170 known, active comets in a formation called the "periodic comets." All these lie roughly in the ecliptic plane and have semi-major axes roughly in the asteroid belt. At least half a dozen are "close" in the ΔV sense.

Shoemaker Table 22aug92 H	Closest Approach to Sun, A.U.	Farthest Distance From Sun, A.U.	Orbit plane, degrees	Earth capture V∞	Velocity at comet	Capture ΔV	Probe ΔV
neo-comet & candidates						**ΔV**	**ΔV**
#4015 1979 VA	1.0	4.3	2.8	8.2	0.1	**4.6**	**6.9**
= Wilson-Harrington Oljato	0.6	3.7	2.5	7.6	1.7	**5.7**	**8.1**
Adonis	0.4	3.3	1.4	7.1	3.2	**6.7**	**9.1**
Ceres	2.6	3.0	10.6	7.3	4.5	**8.2**	**10.6**
neo-comets				km/s	km/s	**km/s**	**km/s**
P/du Toit-Hartley	1.2	4.8	2.9	8.6	0.6	**5.5**	**7.8**
P/Finlay	1.0	6.1	3.7	9.3	0.2	**5.9**	**8.0**
P/Neujmin 2	1.3	4.9	5.4	8.7	0.9	**5.9**	**8.1**
P/Tuttle-Giacobini-Kresak	1.1	5.1	9.2	9.2	0.5	**6.0**	**8.2**
P/Howell	1.4	4.9	4.4	8.7	1.2	**6.2**	**8.4**
P/Haneda-Campos	1.3	5.6	4.9	9.1	0.8	**6.2**	**8.4**
P/Schwassmann-Wachmann 3	0.9	5.2	11.4	9.4	0.6	**6.3**	**8.4**
P/Wirtanen	1.1	5.1	11.7	9.4	0.6	**6.4**	**8.5**
P/Churyumov-Gerasimenko	1.3	5.7	7.1	9.3	0.9	**6.5**	**8.6**
Recently discovered NEO's							
1991 BN (400 m diam)	0.9	2.0	3.4	4.8	0.8	**2.5**	**5.2**
1990 MF (100 m diam)	1.0	2.5	1.9	5.9	0.2	**2.7**	**5.3**
1990 OS (300 m diam)	0.9	2.4	1.1	5.7	0.5	**2.9**	**5.5**
1990 UQ (1000 m diam)	0.8	2.3	3.7	5.6	1.1	**3.4**	**6.0**
1990 UA (300 m diam)	0.8	2.7	1.0	6.1	1.2	**3.9**	**6.5**
1991 BA (10 m diam)	0.7	3.8	2.0	7.7	1.3	**5.3**	**7.6**
Hydrated NEO's							
1988 TA (type C)	0.8	2.5	2.7	5.8	1.2	**3.6**	**6.2**
Ra-Shalom (type C)	0.5	1.2	15.8	4.4	3.0	**4.5**	**7.2**
1986 JK (type C)	0.9	4.7	2.1	8.5	0.4	**5.2**	**7.4**
1987 PA (type C)	1.2	4.3	16.1	9.4	1.2	**6.9**	**9.0**

Figure 5 The table describes the most accessible fuel object candidates. It shows an approximate minimum ΔV a rocket must develop to probe each object, and anything under about 8 km/s is "close." The table also shows an approximate minimum ΔV a space tanker would have to develop to bring a tanker vehicle into captured Earth orbit from each object. Anything under about 6.5 km/s is "close."

Recently discovered NEO's must contain some percent hydrated clay objects. Many of these objects are relatively small and most have very low capture ΔV, less than 3 km/s. The valuable ones never land on Earth because they crush too easily. This makes them explode on entry to the atmosphere. Earth-monitoring satellite data suggests about 3 such events per year occur with delivered energy between 1 and 100 Kilotons (1 kiloton is defined as 1E12 calories). See Jacobs and Spalding (1992) and Wetherill (1992). The close hydrated clays are exceptionally attractive because of their easy access and short trip time.

Mass Payback

How much more payload do we get back compared to the machinery launched to get it? Suppose we launch just an empty space tanker, fuel it from space, and use it to haul payload back to Earth orbit. What is the ratio of payload to tanker? What are the essential elements of a space tanker? Suppose we can choose to use chemical propulsion, also fueled from space, or steam propulsion or hydrogen propellant, NTR's. Which would haul the largest payload? Suppose we operated the steam NTR reactors at far below their rated maximum temperature, for whatever reason. How would this affect payback?

Figure 6 sketches the basic elements of a space tanker. The propellant or fuel, contained in the innermost bladder, is fed to the rocket engine attached to the structure. The payload, water, is frozen by space and engulfs the propellant bladder as an armoring shield. Insulation is placed between the propellant and armor. The tanker performance is a strong function of the engine performance, measured by its specific impulse, and the tank capacity per tank mass, measured as a ratio.

The tank mostly needs to be strong enough to contain the vapor pressure of the propellant or fuel. But it may not need to provide much structure to hold the fuel in an acceleration, like it would if it were resting on the surface of the Moon, the Earth or Mars.

Figure 7 shows the payback ratio for an entire family of propulsion and tank performances. The figure plots payback as a function of rocket performance, measured by the specific impulse in kilo-seconds.The family of curves represents the effect of propellant tank performance. This in turn reflects the conditions in space where the system does not need to accelerate very much.

The figure shows that specific impulses between 0.150 and 0.250 kilo-seconds can result in payback ratio's in excess of 100 to 1. The tank performance in the range of 500 to 4000 represents a tank similar to a garbage bag bladder. A 1/2 pound garbage bag can hold about 32 gallons of water, or about 500 times it mass. But only if the bag is in zero G, as one could simulate by filling the garbage bag with water in a swimming pool. Calculations indicate that water bladder tanks holding in excess of 4000 times their mass can be readily constructed for these applications.

The data for this figure is patterned after Zuppero (1992). A ship using 20 tons tanks, 20 tons engines and structure and developing 8 GWatts thermal for 1 day would deliver about 10,600 tons to HEEO.

Note that a water reactor operating between 500 C and 1200 C provides the required specific impulse. These reactors use well developed technology.

The most un-intuitive feature of the figure is that in all cases, increasing the rocket performance beyond a limit results in rapidly diminishing payloads.

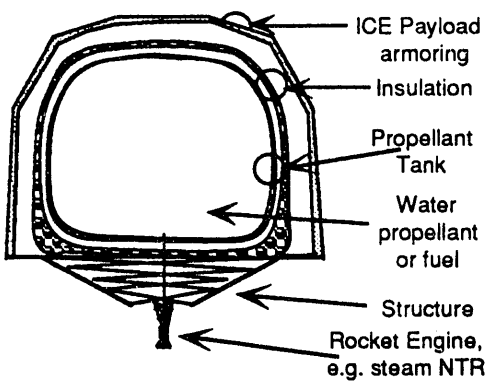


Figure 6 A space tanker consists of a rocket engine pushing on a structure that holds the propellant or fuel tanks, and the payload.

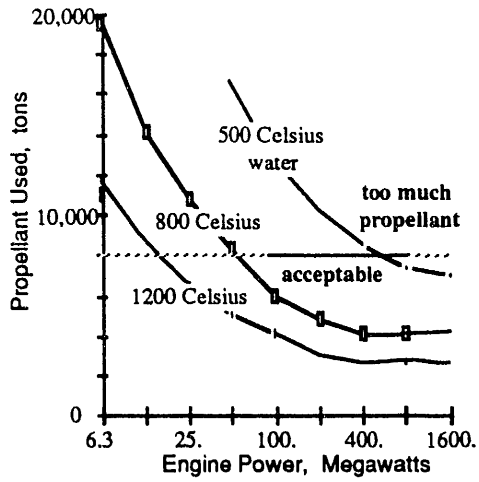


Figure 8 A low power, low weight rocket engine can deliver large payloads at the cost of propellant --gravity loss. But the surprise is that the the loss remains reasonable even with engines as low as 25 Megawatts for delivered payloads of 500 tons from neo-comets.

Power Reduces Waste

What range of propulsion power is required to effect a capture? The measure of performance is the propellant wasted. As the decelerating rocket power goes up, the capture maneuver time at Earth becomes smaller and smaller, the maneuver approaches a perfect one and the propellant waste factor, called "gravity loss," approaches zero. Figure 8 shows that to return a 500 ton payload from an object with mission ΔV like that of VA would require steam reactors between 25 and 500 Megawatts. Powell and Ludewig (1989) calculated 3000 Megawatt reactors would weigh less than 4000 kg. Systems using these reactors are small enough to be launched using today's Titan IV.

Cost Estimates

How much would the fuel cost? A spreadsheet model suggests that if a program to provide the fuel charged $3000 per pound to go to orbit, and 4 times that much for hardware, then the cost of the fuel could be less than $100 per pound, as shown in Figure 9. The model assumed 2 year orbit round trips, like missions to the NEO Apollo. This first situation assumes the users would not pay to amortize the development of the vehicles or the infrastructure.

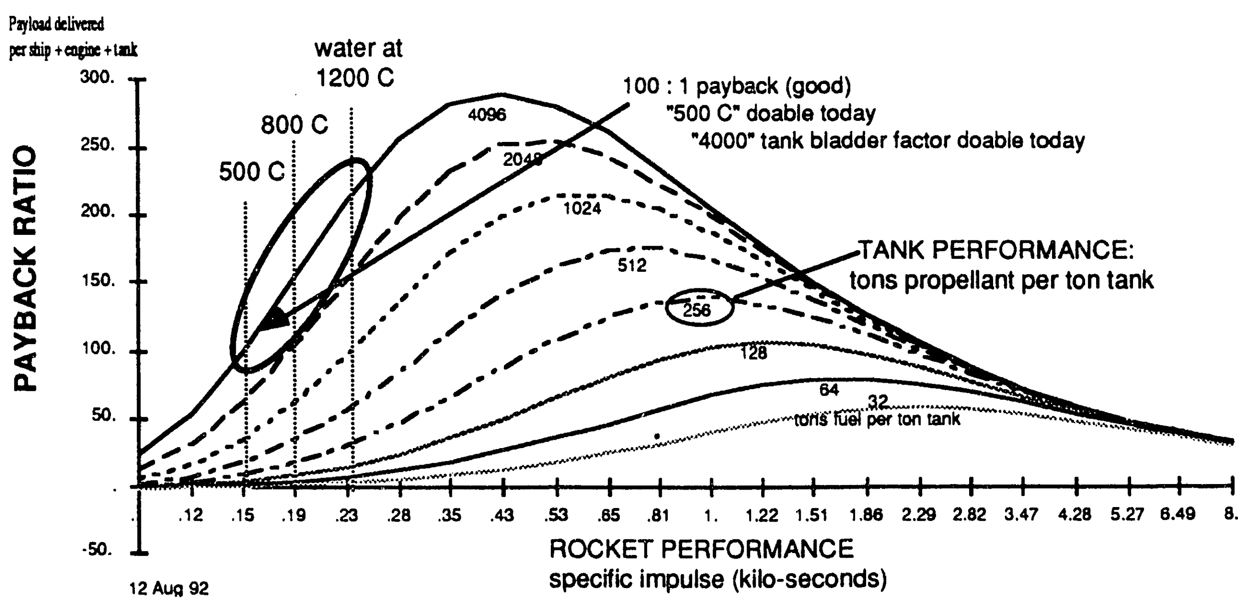


Figure 7 The payload returned per launched tanker can exceed 100 to 1 for a nuclear heated, steam rocket propelled space transportation system. The key is that the rocket fuel (propellant) is entirely supplied in space and is not launched.

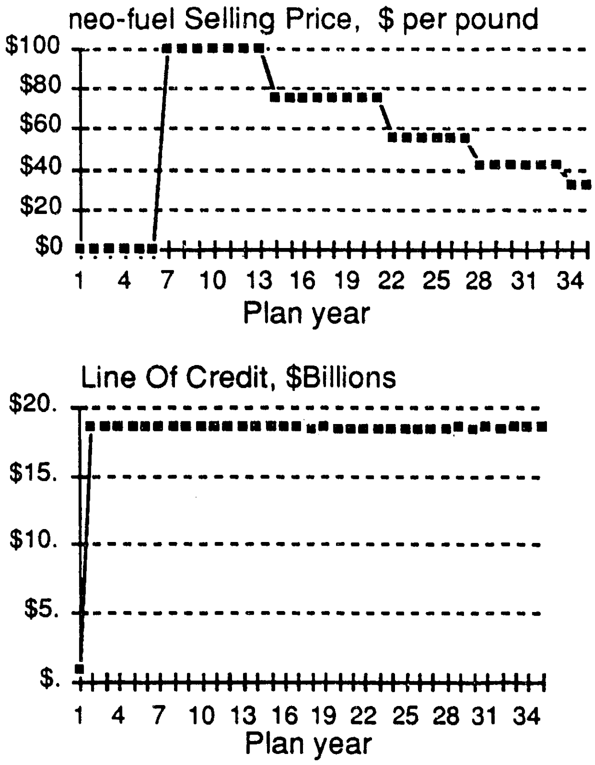


Figure 9 Users would pay of order $100 per pound for the neo-fuel if the space transportation system were funded like a government program. The Line of Credit to put the architecture in place would be completely funded by government. This could be like the initial system.

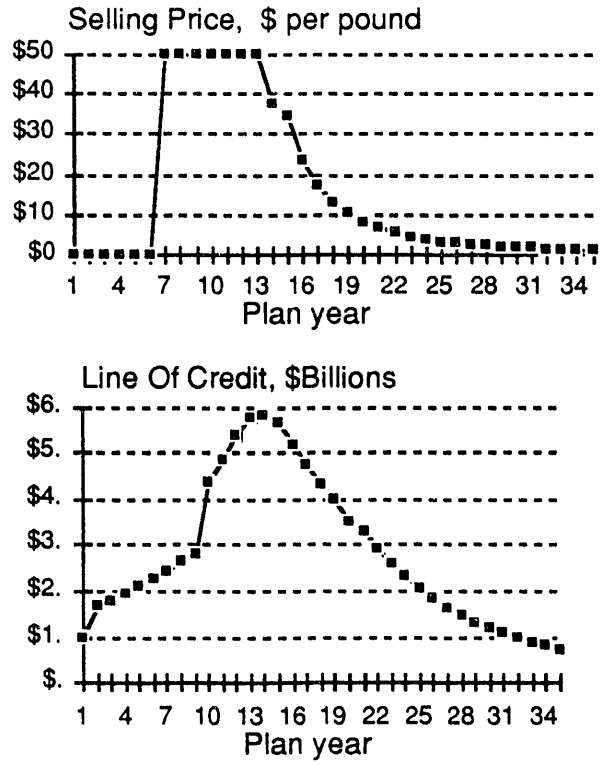


Figure 10 Costs to users could plummet exponentially to ~dollars per pound if a launch system can be used that charges $100 per pound to LEO, from Earth. Investors would completely pay off their line of credit at 8% interest.

The second situation models a commercial venture. A line of credit at 8% interest pays for development and to use some future, commercial launch system that delivers payloads to orbit for $100 per pound. Figure 10 shows that after an infrastructure building period the costs appear to plummet exponentially. This result is strongly dependent on the trip time for the NEO orbit and on the mandate that the line of credit be nearly completely paid off at the end of the program, with 8% interest.

The cost of neo-fuel is some fraction of the cost to go to orbit. Low cost to orbit means permit low cost development of space machinery.

Manned Missions using neo-mass

Neo-mass enables massive manned space vehicles from modest mass launches. Both water and liquefied refractories readily freeze to a solid in space. We can use this property to construct massive ships by launching only the mold from Earth. We would construct the bladder mold to provide meters-thick walls and oblate cylinder shapes. We would inflate the bladder-like mold with neo-mass, such as water or melted slag from space. When the injected material solidifies, we would rotate the vehicle, creating an artificial gravity in its large volume, inner regions. Such a vehicle would also provide the required shielding from both Galactic Cosmic Radiation and Solar Flares. These are the two most crippling problems we need to solve before people can take long, several year journeys in space. By providing enough space per person, we also solve the most pressing psychological problem of space, that of confined living spaces. Some occupants might become dizzy, just as some oceangoing passengers get seasick.

For example, a space vehicle shaped like a racing tire with 1 meter thick ice walls, with 34 meters dimension and rotating at 8.3 seconds per revolution would weigh 2000 tons. At the volume locations where a person would experience between 1/2 and 1 G it would provide about 90 living spaces each as large as a very large motel room of 92 cubic meters. If the mold were made of advanced carbon fiber composites it would weigh less than 13 tons. The mold would be strong enough to hold 1/3 atmospheric pressure and support water fluid undergoing the 20 milli G acceleration of a trans-Mars injection maneuver from high elliptic Earth orbit. This very large, biologically and psychologically safe, affordable launched space ship would require only modest Earth launches. The neo-mass could be delivered from neo-comet (4015) using systems launched using existing launch systems and facilities.

By the same token, a ship to hold 1000 people under similar conditions would weigh about 10,000 tons. This amount of mass would be delivered by a space tanker weighing about as much as the USA Space Shuttle. The launched mass would be hundreds of times less than the ship mass. A 20 ton steam nuclear thermal rocket would use about 30,000 tons of water propellant to take such a ship on the 9 month journey from Earth to Mars. All these factors suggest that the discovery of neo-mass would enable affordable industrialization of the solar system from Mercury to Jupiter.

Program First Step: Verify

Our first step would be to verify that we have indeed found a useful resource. The inventors and their peers need to convene to assess the impact of the recent discoveries of rocket fuel materials in the space near Earth, including an assessment of the state of the art of the required compact space nuclear propulsion and power systems needed to exploit these resource discoveries.

We would then need a prospecting and assay program. The new resources lie somewhere between the hidden poles of the Moon and the orbit of Jupiter. We need telescope searches to find and spectrally characterize which of the 208 known NEO's are the best candidates to send probe vehicles to. Telescopes and astronomers are inexpensive compared to aerospace activities.

We would send fly-by probes and lander/sample vehicles. About 20 candidates are identified today as very good, and comet 1979 VA has zero risk for water content. We would propose sending small, nuclear powered probes to fly by and land on the micro-planets, and penetrate and analyze their soils for resources. Nuclear power sources enable missions launchable using existing launch systems. Preliminary calculations indicate between 20 KW and 200 KW electric would be required.

Similar, nuclear powered robotic probes would collect and return samples from NEO comets. Nuclear propulsion lowers the launch weights enough so that existing rockets can lift them to orbit.

Summary

This August 14, 1992 an active comet named (4015) 1979 VA = Wilson Harrington, has been reported in the swarm of asteroidal, near Earth objects (NEO's), whose orbits cross or come close to that of Earth. It would provide massive quantities of water to be used either as rocket fuel ore or directly as rocket propellant. Engineering analysis discovered that even the simplest nuclear heated steam rockets would enable the return of massive quantities of the comet's water to earth orbits. Calculations estimate that the cost to users could lie somewhere between $5 and $100 per pound. The first uses would be as rocket propellant or fuel to take commercial satellites from low orbit to their operational high orbit.

A swarm of near-earth objects (NEO's) has been observed in recent times, and theory indicates a substantial fraction of them should be similar to (4015). The key features making these objects useful are 1. they contain water ice, 2. they have near zero gravity, making them very accessible, and 3. they are relatively close to Earth.

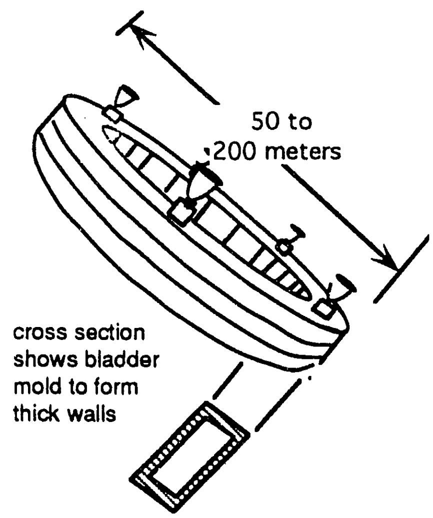


Figure 11 A balloon mold shaped to inflate into the form of a space ship would allow low mass launches to result in high mass, large space ships. Such slowly rotating ships, inflated with neo-mass, would provide nearly complete protection from Galactic Cosmic Radiation, Solar Flares, zero gravity sickness and cramped-space discomfort.

The first program to exploit the discovery of neo-fuels and neo-masses would send probes to the most promising objects identified by ground based telescope searches. The vehicles would first assay and characterize the comet material and then send samples back to Earth orbit. About 208 candidate objects are known (as of 22 July 1992), of which about 50 are expected to be good targets.

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