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An Analysis of Current Space Exploration Options

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All of us in this room have been lucky enough to witness the beginnings of man's journey into the heavens. We are also participants, willing or not, in some of the most profound environmental and social challenges ever to confront our species. Only in the past 60 or so years have we had the ability to destroy our own kind either with nuclear weapons or as is becoming increasingly clear with each passing day, by our profligate callousness to our own planet and its exquisitely tuned biosphere. My talk today will attempt to make the argument for two space based technologies that may offer a potentially species saving option for us all. I believe that the choices we make as a species right now are critical to ensuring our survival and mandate immediate action if our children and grandchildren are to inherit a livable planet. We are living on the tip of a very sharp knife.

We will review lunar mining of Helium-3 (He 3) and its applications in second and third generation nuclear fusion reactors as well as the feasibility of a planetary asteroid and near Earth object protection system. This will be contrasted with the incredibly exciting, but in my opinion, less urgent goal of interplanetary manned exploration of Mars and our neighboring planets.

Nuclear fusion power is the next evolutionary step in man's attempts to provide a readily available, environmentally non-destructive form of energy production and it offers tremendous advantages over petrochemical and nuclear fission type power production. The nuclear fusion reaction occurs when two light atomic nuclei are fused together to form a heavier nucleus and in doing so release energy. The basic concept behind any fusion reaction is to bring two or more atoms close enough so that the strong nuclear force in their nuclei will pull them together to form one larger atom. If two light nuclei fuse, and light atoms are considered to have a lower atomic number than Iron for this purpose, then they will fuse and form a single nucleus with a slightly smaller mass that the sum of their original masses. The difference in mass is released as energy according to Einstein's mass equivalence equation where E=mC2. Any difference in mass will be multiplied by the value of the speed of light squared, a truly awesome number. As an aside, atoms with a heavier mass than Iron will release energy in a nuclear fission not a fusion reaction.

Fusion between atoms is opposed by their positively charged nuclei. In order to overcome this electrostatic force, some external source of energy must be supplied. The most efficient method is to heat the atoms, which has the side effect of stripping the electrons from their nuclei so that they exist in a fluid known as plasma. The containment of this highly energetic plasma is usually done with electromagnetic techniques and is one of the most difficult technical problems facing the designers of fusion reactors. Plasma is jokingly referred to the "naughty child" of nuclear fusion by designers since it is so hard to contain.

Let me just say a brief word about atomic terminology. An atom has a nucleus consisting of positively charged protons, electrically neutral neutrons and negatively charged electrons. The electrons orbit in cloud-like shells at various distances from the positively charged nucleus. An atom with the same number of protons but variable number of neutrons is called an isotope. For example, hydrogen exists primarily as protium, which has one proton, one neutron and one electron. Heavy isotopes of hydrogen are deuterium which has two protons and all else remaining the same and tritium has three protons. Helium with two protons has isotopes with one neutron, called He-3, the possible hero of our story and also as He-4 with two protons.

Our Sun is a Hydrogen-Hydrogen nuclear fusion reactor that creates Helium. The reaction takes place at a temperature of 15 million degrees and a pressure of 100,000 atmospheres. These conditions are impossible to reproduce on Earth, so terrestrial fusion reactors must operate at lower pressures and higher temperatures of about 100 million degrees.

Mankind's first experiments with fusion produced thermonuclear weapons, which can produce roughly 500 times the yield of fission weapons such as the original Hiroshima type atomic bomb. A hydrogen bomb uses energy released by a fission weapon to compress and heat fusion fuel to detonation. It took about 10 years to go from fission weapon development to the first experimental nuclear fission reactors. The first ideas for nuclear fusion power production included the concept of detonating fusion weapons in an underground chamber and using the heat to generate steam and turn a turbine apparatus, clearly not a very practical arrangement. The first patent for a fusion type reactor is credited to the United Kingdom Atomic Energy Authority in 1946 and defined the basic principles including a toroidal vacuum chamber, magnetic containment and radio frequency plasma heating. The US fusion program began in 1951 and led to the creation of the Princeton Plasma Physics Laboratory which is still active today. This is an example of a first generation fusion reactor using two heavy hydrogen isotopes, deuterium and tritium, which fuse at lower temperatures than ordinary hydrogen.

The most common current scheme is the Tokamak, a doughnut shaped device where two magnetic fields are combined to confine the plasma. It was first developed in the mid 1950s by Sakharov in the Soviet Union. The world's largest Tokamak is a deuterium-tritium reactor called JET, the Joint European Torus, located in Culham, England. Using the JET, scientists have heated plasma to 300 million degrees. Unfortunately, the fusion power production is slightly less than the power put into the plasma. It has maintained an output of 16MW for a few seconds however long term radioactivity of the generator is an engineering limitation. It will require remote handling for years to come due to the unwanted production of radioactive neutrons in the D-T reaction. Other upcoming projects include a smaller Tokamak called MAST which keeps the plasma in a tighter configuration and is more energy efficient .

A so called second generation fusion reactor, such as the one found at the University of Wisconsin Fusion Technology Institute substitutes He-3 for tritium. This significantly reduces neutron production, making it safe to locate a fusion plant near a large city for example. The deuterium and He-3 reaction uses electrostatic confinement, rather than magnetic confinement, thereby simplifying design.

A third generation reactor is theoretically possible using only He-3 which can directly yields He-4 and 2 protons thereby producing electricity directly through the use of solid state conversion materials, without the need to turn a turbine and power a generator. Potential conversion efficiencies of 70 percent may be possible. This technology is the least developed at present.

Other advantages of this technology include the fact that He-3 is not radioactive. Also there is no potential in a fusion reactor for a meltdown type malfunction such as we have seen in Chernobyl and almost saw at Three Mile Island. The key difference is that with fissionable materials the heat generated by beta particle decay can continue for several days after the reactor is shut down and destroy the reactor and its containment vessel. With a fusion reactor, a mechanical breakdown would cut off the supply of fusion fuel and incapacitate the mechanisms necessary for the reaction to continue and would turn off the reaction by cooling the reactor down to the point of non-reactivity. Helium is not a greenhouse gas and the 12 year half life of tritium is quite manageable.

Well we all know that there is no such thing as a free lunch; so what are the associated problems? Current estimates are that the first viable commercial second generation fusion reactors are not likely to be available before 2050. Assuming that the engineering issues can be solved, and I think that a Manhattan project or Apollo space program scale investment of resources on an international level is justified, then the main problem will obtaining the necessary He-3 as a fuel source.

Vast quantities of helium originate in the sun, a small part of which is He-3 rather than the more common He-4. Both types of helium are transmitted through space as they travel toward Earth as part of the solar wind. This isotope never reaches Earth due to repulsion by the Earth's magnetic field. He-3 was trapped in the mantle of the Earth during our planets' formation and is present in the range of 100,000 to 1,000,000 tons. However it is inaccessible in this region. About 3 kilograms per year of He-3 are emitted in the mid ocean ridges, the atmosphere, volcanoes, and in a few other non-useable sources as He-3 leaks out of the mantle. Unfortunately, extraction of terrestrial He-3 would consume 10 times the energy available from fusion reactions it would be intended to power. About 150 kg has been recovered from the decay of tritium in US thermonuclear weapons and this is the current source for experimental purposes.

Abundant He-3 is thought to exist on the Moon embedded in the upper layer of regolith or lunar crust, deposited there by the solar wind over billions of years as well as in the solar system's gas giants left over from the formation of our galaxy. Different sources give varying estimates for Lunar He-3 deposits. Samples collected in 1969 by Neil Armstrong showed that He-3 concentration in lunar soil is 13ppb by weight with estimates of 20-30ppb in undisturbed soils. Other sources estimate 0.01ppm. This is a large variance that I cannot explain based on my research sources and is of obvious importance. Different regions in the moon will almost surely yield different concentrations of accessable He-3. Digging a 3/4 mile square area of the moon to a depth of 9 ft. would yield about 220 lbs of He-3, enough to power a city the size of Dallas or Detroit for a year. It is envisioned that automated mining machines would be utilized. This would be followed by an extraction process consisting of heating and agitation to release gasses trapped in the soil followed by cooling to near absolute zero to separate the gasses and then a final step of separation of the gasses through a special membrane. This all presupposes a viable Lunar colony. The technology required for a Lunar colony is thought to be solvable, but will include the need for water, shelter, food, power, protection from meteorites and cosmic radiation (remember there is no protective atmosphere on the moon), as well as the psychological and physiological stresses and challenges of living in an environment with zero tolerance for error.

There is also a need for new rocket technology for transport. The Saturn V was capable of lifting 50 tons to the Moon. However, incredible as it may seem, someone at NASA threw out the blueprints for this behemoth. Reverse engineering is not very efficient, as the project to recreate the 1903 Wright Flyer in 2003 demonstrated. Serious attempts at exact reproduction by capable people in that case failed to produce a working aircraft .In any case, a new heavy carrier called Aries 5 is being developed to lift 100 tons of payload for the Mars project. This is an evolutionary not revolutionary step and should be solvable. Unmanned transport flights carrying supplies to the moon and products back from it would be common and require an economical transportation system. One imaginative solution is the electromagnetic sled, a device that accelerates a payload along a several mile long track by means of sequential electromagnetic activation until earth orbital escape velocity, 17,600 mph or so is achieved. I would think that a lunar based device would be even more efficient given the very weak gravitational field of the moon.

Let us be clear, there is no immediate prospect for commercially viable fusion power and its implementation may be many decades away. The establishments of a moon base and transport technology are also long term projects but the possibilities of this combination are dazzling. An unlimited, relatively clean and non-greenhouse producing source of energy would eliminate the need for petrochemical fuels. The estimates for the cost of the power produced by fusion range from similar to the cost of current energy production to several times higher than the alternatives, it is very difficult to say since we don't know when we will have a successful fusion reactor. Further R&D for fusion technology alone is estimated at 80 to 110 billion dollars over 50 years. Former Apollo 17 astronaut, US Senator, geologist and lunar mining advocate, Harrison Schmitt estimates $5 billion to update the Saturn V to lift a payload of 100 tons to the lunar surface for less than $1,500 per pound. He estimated $15 billion for a lunar colony.

Our solar system is a very crowded and active place. Impact events are caused by the collision of asteroids or comets (generically called bolides or near earth objects) with planets. The moon is likely the product of such an event in the Earth's history about 4 billion years ago. In the past century we have recognized the evidence of countless previous impacts on other planets by telescope and space probe photography, and we have actually seen the impact of the Shoemaker-Levy 9 comets with Jupiter in 1994. Based on crater formation rates determined from the Moon, astro-geologists calculate that during the last 600 million years, the Earth has been struck by 60 objects of a diameter of 5 kilometers or more. The smallest of these impactors would release 10 million megatons of TNT and leave a crater 95 kilometers wide. The largest man made thermonuclear blast was 50 megatons by comparison. During that same 600 million year period there have 5 major mass extinctions that on average extinguished half of all species. The largest mass extinction occurred 250 million years ago and killed off 90% of the species present in the Permian period. Scientists from Ohio State University have located a 483 km. crater beneath the East Antarctic Ice Sheet which may date back about 250 million years ago and which might be associated with the Permian-Triassic extinction event. In

1980 scientists from UC Berkeley changed the scientific world's view of Dinosaur extinction from one of gradual multiple environmental causes to a catastrophic bolide impact that occurred 65 million years ago. The Cretaceous-Triassic boundary marks the absolute disappearance of the Dinosaurs worldwide and is associated with extremely high levels of Iridium, an element found in high concentrations in meteorites. The impact site is likely the Chicxulub crater found underwater near the Yucatan peninsula. It is 180 km. wide and its impactor is estimated to have been 10-14 km. in diameter. Scientists now believe that we have many near misses per decade that we have been completely unaware of. By the way, not all bolide impacts are bad. There is an active theory call Pan-spermism which states that life on Earth and other places may be spread by interplanetary cosmic collisions such as meteorites.

In 1998 Congress directed NASA to find 90% of Near Earth Objects or NEOs that are at least 1 km. wide, about the size of a civilization ender. So far the Spaceguard Survey has cataloged more than 800 asteroids of that size, out of a projected population of 1100. A few years later, Congress upgraded its requirements to include 90% of NEOs 140 meters wide, an object large enough to take out England or Northern California for example. The Spaceguard estimates are an impact frequency of one per 1,000 years for small atmospheric penetrators of 50-100 m. and a frequency of one in 500,000 yrs for a 1 km. size impactor. A period of 7-20 yrs. is necessary to catalog 90% of the NEOs in this range at a cost of $230-$400 million.

Currently there are 6 Earth based telescopes in the Spaceguard effort. A Lunar based telescope system has been proposed, with a telescope placed in the northern and southern Lunar hemispheres. They would provide a complete survey of the skies with very high resolution due to the lack of atmospheric distortion. A series of orbiting telescopes is also a possibility. It is intuitively obvious that less force delivered to alter the course of a potential impactor is necessary if it is delivered farther away from earth. Detection times are therefore of vital importance to a planetary defense system.

Not all NEOs are built the same. Asteroids range from primarily stony to mostly metallic, with various proportions of each type of material, and they may contain deep, powdery regolith which can affect deflection efforts, particularly landing and attaching to the object. Comets, which travel into and out of our solar system, contain a mixture of non-volatile materials as well as large amounts of frozen volatiles which can produce a diffuse cloud around the nucleus called a coma. We may have to deflect or blast what is in essence a clump of metal, a hard or porous rock or an icy mass depending on the circumstances.

NASA's NEAR (near earth asteroid rendezvous) spacecraft was launched in Feb. 1996 and accomplished a controlled descent to the surface of the asteroid #433 Eros, more than 196 million miles from the Earth. It returned breathtaking photos of the boulder strewn surface and gathered information on the interactions of Eros with the solar wind and as well as information on asteroid spin. It was rather modestly described in the NASA website as "mechanically simple...with only one moveable mechanism". Power was provided by solar panels. X Ray, Gamma Ray, Laser Rangefinders for surface mapping and a Magnetometer were also on board the octagonal shaped spacecraft which measured only 1.7 m. per side. Not bad for a design about 25% the length of thefamily SUV. The Japanese space probe Hayabusa (Falcon) approached the asteroid Itokawa to within 130 feet in 2005 but was unable to complete its objective of landing on the asteroid and returning a sample of it to Earth due to a faulty attitude controller. It was 180 million miles from Earth at that time.

So we can see them, or at least see some of them, and we can touch them, what now? There are a number of creative options. A direct nuclear assault on a NEO could cause fragmentation and the radioactive contamination of a rubble pile that might still impact the Earth. A nuclear blast several hundred meters away from the surface might do the job by vaporizing the exposed surface of the NEO and changing its trajectory. A more subtle approach is to employ a laser to ablate a surface of the NEO and change its spin or mass. A spacecraft that lands on the NEO and changed its course by a reaction or nuclear powered engine has been proposed. Solar sails, designed to in deep space could be harnessed to the NEO and adjust its course by reflecting the radiation pressure from light on the sail. This technology is currently in used to a limited to degree on interplanetary probes. Even a deflection as slight as 1% at a distance of 100 million miles would produce a very large miss. For example, a nudge of just 1 mph would change a NEO's location is space by about 170,000 miles after 20 yrs. Objects discovered nearer to the Earth would require a more robust and quicker defense.

Finally, in Jan. 2004 President Geo. Bush outlined an ambitious program to explore the Moon and Mars with manned missions. He asked Congress for $800 million in seed money in 2005 and an additional 5% over NASA's annual budget of $15 billion. The manned program to Mars was estimated at a cost of $40-$80 billion. This current project proposes the so called Mars Direct Plan and begins with the launch of an unmanned Earth Return Vehicle that will on land on Mars and manufacture its own propellant, thereby laying the groundwork for the arrival of astronauts. Two years later, a manned spacecraft and another unmanned ERV land at the previous landing site, while the ERV prepares for the next manned mission , scheduled to arrive in another 2 years. Once again, upgraded chemical reaction rocket technology and an Apollo style spacecraft significantly scaled up are key components. They are available today and require modification from existing designs. The alternative scheme of bringing all the fuel necessary for the mission directly from Earth was estimated to cost $800 billion. Major hurdles to overcome include the need for artificial gravity, protection from cosmic and Mars based radiation, food, climate and medical issues, dust storms, potential in-flight medical emergencies and the considerable psychological stresses of prolonged intense confinement in space with other people.

In summary, I feel that our best options at this time are the commitment to a Planetary Defense system and to the development of a viable nuclear fusion program, fueled by He-3 obtained from lunar mining. The first is relatively inexpensive. Although it is admittedly a defense against a very infrequent event, geological and astronomical observations prove that while it is statistically relatively infrequent when compared to a single human lifespan, it is a certainty given enough time. It is also now at least partially predictable and preventable. In keeping with Athenaeum tradition, we can say that a sizable bolide impact with the Earth would have a Hopkinsville connection, albeit a very bad one.

The fusion option could free us of our thirst for petrochemicals and potentially help save us from a global warming catastrophe, if it can be developed quickly enough. Of course other energy sources, such as wind power, geothermal etc. should be developed but fusion is so powerful and revolutionary that it cannot be ignored. International cooperation for the development of fusion technology and the establishment of a viable Lunar mining base in my opinion should receive immediate and wholehearted support for the good of all. I do not think there is much time to waste here.

The goal of a manned mission to Mars, scheduled in the next 25 years is noble and inspiring, but I think will distract efforts from the first two options and should be postponed. The commonly stated goals of developing new technology can be surely be satisfied with a lunar mission and the discovery of evidence of life on Mars, current or past, can be accomplished by robotic means. The argument that humanity needs another planet as a back-up to insure the survival of our species is, forgive me, specious since we seem to be the biggest threat to our own survival. We don't need to go to another planet to correct this; we need to fix our problems on Earth, here and now. We need to grow up and soon.

These projects hold great promise and are among the most exciting ventures ever contemplated by Mankind. Let us seize the opportunity and we can leave the planet a better place for our children.

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