IS EXTRATERRESTRIAL HELIUM-3 THE ENERGY SOURCE OF THE FUTURE?

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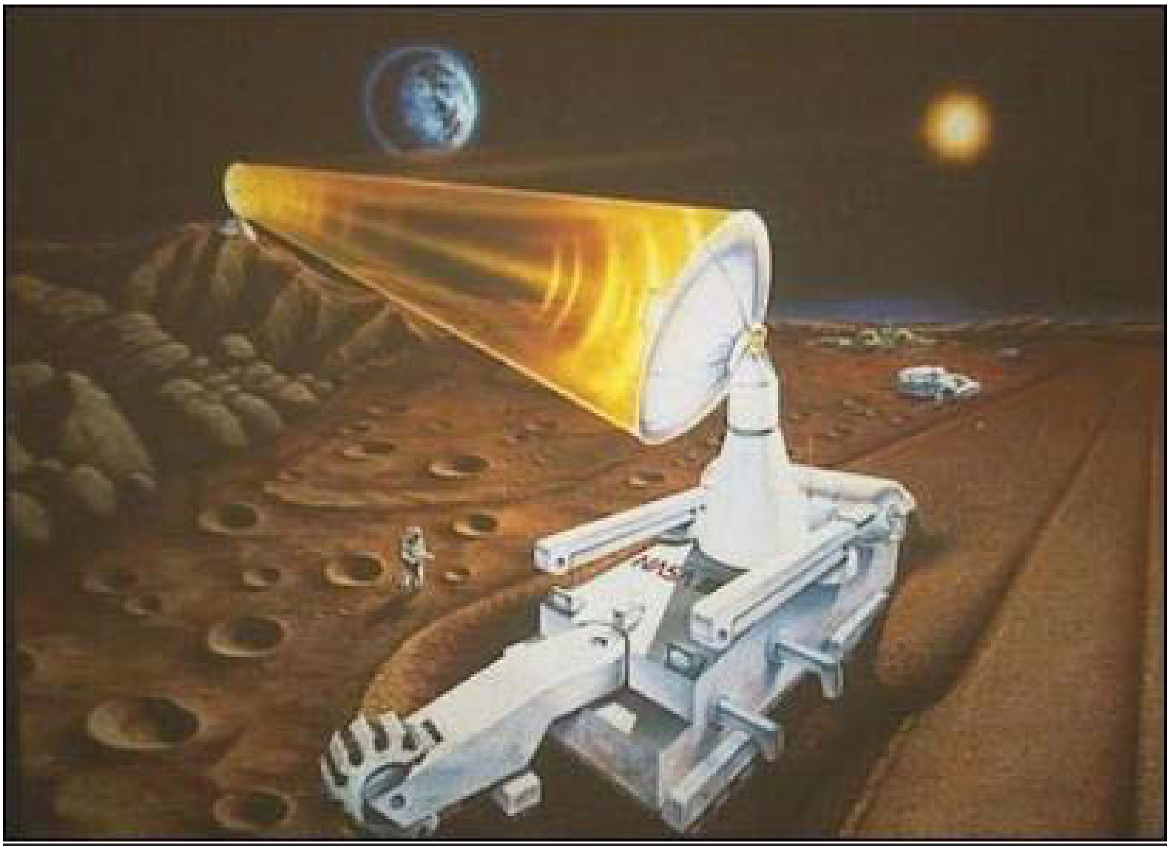

Figure1-Artist's impression of a lunar volatiles miner [1]

Abstract

The search for new sources of energy is a vital issue of the 21st century. It is unquestionable that the next 100 years will be the site of an energy crisis, and new forms of power generation will be necessary to overcome it. One such alternative energy source is the fusion of Helium-3, which is a clean and highly energetic source of nuclear power. Helium-3 is an isotope of Helium which is rare on Earth, but exists in large quantities on extraterrestrial sources such as the Moon and the Gas Giants of the Solar System. Ways have been proposed to harvest the extraterrestrial Helium for use on Earth. The amount of energy contained in the extraterrestrial Helium-3 is so tremendous that it would easily secure humankind's energy needs, and in the long term could find other, more speculative uses. This paper is a survey of this broad topic.

1. Introduction

“There is not the slightest indication that nuclear power will ever be obtainable”.

These words were spoken by Albert Einstein in 1932 *[2]*. Over the following few decades, nuclear energy has completely revolutionized mankind’s conception of energy generation and the orders of magnitude involved. The energy which can be produced through 1 kilogram of uranium fuel is roughly equivalent to the energy contained in 17 000 kilograms of coal *[3]*. The discovery of obtainable nuclear energy can only be compared to the invention of the steam engine in the eighteenth century. Today 11% of the world’s energy is produced through nuclear fission reactors *[4]*.

Nuclear power has, however, always been a subject of controversy. Proponents claim that it will be the only solution of the inevitable energy crisis of the 21 century. The currently used fossil fuels will be depleted within the next 100 years, while humanity’s energy demand will have increased by as much as three times *[5]*. An alternative to nuclear power would be renewable energy sources such as solar energy or wind power. However, those have been criticized as being too dependent on geographical and climatic factors, and for the limited amount of energy which they can produce *[6]*.

Critics claim that nuclear energy is very risky and harmful to the environment as it produces radioactive waste products *[7]*. Also, there is always a probability that the reactor malfunctions, which would cause radiation to be released into the environment, as has happened during the Chernobyl Disaster in 1986 *[8]*.

The two parties would be reconciled if a form of nuclear fusion without radioactive waste would be obtained. The fusion of Helium-3, a rare isotope of Helium, is such a reaction. It is superior to other nuclear reactions in every conceivable way, but it requires very high temperatures to operate *[9]*. Also, it does not occur in significant quantities on Earth, so extraterrestrial sources such as the moon, but also the gas giants of the solar system, would need to be mined to obtain a significant amount of the fuel.

But if humanity will become able to use extraterrestrial He-3 as a source of energy in the future, it will radically change the role of nuclear power, but also of space travel, to society, and will lead to fantastic possibilities.

2. Nuclear Power

In nuclear power, energy is produced through controlled nuclear reactions, which are *fission* and *fusion*. In both processes, some of the mass of the reactants is transformed into energy. While the percentage of the transformed mass is small, according to $E = mc^2$ the energies released are still vast, which makes nuclear energy an attractive power source. Another way of looking at this is to consider that the energy released in nuclear reactions is connected to changes in the nuclear binding energy, while chemical reactions are connected to changes in electron binding energies in atoms *[10]*. Nuclear binding energies are several orders of magnitude larger than electron binding energies, which is the reason why nuclear reactions are so much more powerful than other methods for power generation *[11]*, and are the chief contender to solve the inevitable energy crisis.

2.1. Fission

At present, all nuclear power stations are based on fission. In that process, a nucleus splits into several smaller nuclei, and several neutrons. In order for a fission reaction to release energy, the nuclei which are used must be “heavy”, which means that they must have an atomic mass A higher than about 60. Those heavy nuclei are less stable than those with $A \approx 60$, so that they can undergo fission into more stable nuclei, thereby releasing energy *[12].* The energy is equal to the “mass defect”, as the masses of the resultant nuclei are smaller than the mass of the initial nucleus.

Controlled Nuclear Fission, which has been thought impossible in the first decades of the twentieth century, and has been referred to as “moonshine” by Ernest Rutherford in 1933 *[2],* first came into commercial use in the 1950s *[13],* and has since then become an indispensable source of energy worldwide. The two isotopes which are used for fission power are uranium 235 and plutonium 239 *[14].*

However, Fission has always been criticized for numerous reasons *[7]*: Fission products are frequently radioactive with half lives up to several 100 000 years. Additional radioactive waste is caused by neutron activation, when structural components of the reactor capture neutrons produced during the fission and become unstable themselves. There is a big problem disposing of the radioactive waste, and isolating it from the biosphere for the enormous periods of time required. Also, there is the risk that radiation is released into the environment due to reactor malfunctions. An additional, purely technical, issue is that the released, highly energetic neutrons cause damage to the reactor itself.

2.2. Fusion

Scientists had initially hoped that mastering controlled nuclear fusion would allow them to solve these problems *[7]*. It was hoped that fusion would be a clean power source, and thus would radically change the public perception of nuclear energy.

In nuclear fusion, energy is produced when two atomic nuclei merge into one, forming a new element as well as a free neutron or proton. Thereby, the nuclei have to be "light", they must have mass numbers less than 60. The mass of the resultant nucleus is smaller than the masses of the reactants, so that mass is transformed into energy *[12]*. Fusion is capable to produce a much greater amount of energy than fission. If one were to fuse a set mass of deuterium, it would produce four times the energy produced by the fission of the same mass of Uranium 235 *[15]*. A massive advantage of nuclear fusion is that the nuclei produced through this reaction are generally not radioactive, which seems to be a step away from the mentioned radioactive waste problems, and towards clean nuclear power.

However, fusion reactions are more difficult to accomplish, as nuclei are repelled due to electrostatic forces, forming a "Coulomb Barrier". The nuclei need to be brought to very high kinetic energies (i.e. temperature) to get sufficiently close to each other for the strong interaction between them to take over and initiate fusion *[16].* The temperatures required are of the order of 100 million Kelvin *[17]*, which causes an additional problem of confining the particle plasmas. Magnetic Fields have been proposed as a solution *[17]*.

In the past decades research has been conducted into making fusion a practically usable energy source *[18]*. The fusion reactions which would be easiest to accomplish are the fusion of the Hydrogen isotopes Deuterium with Tritium (D-T fusion), and of Deuterium with Deuterium (D-D fusion). This is because the Deuterium and Tritium Nuclei are singly charged, so that the Coulomb Barrier is easier to break. A major problem with both these reactions is that both would still produce free neutrons which would, as in the case with Fission, lead to Activation Products and radiation damage *[7]*. Also, tritium itself is radioactive and has to be contained. So these fusion reactions could reduce, but would not solve the radioactive waste problem. As both produce energetic neutrons, neither would solve the problem of radiation damage.

3. The fusion of Helium-3

If nuclear power is to fulfill mankind's energy needs in the coming century, it needs to be utilized on a massive scale, which means that it would be necessary to minimize all types of nuclear waste and damage. The solution could be using a different isotope for the fusion: Helium-3. Helium 3 is an isotope of Helium which contains 2 protons and 1 neutron, as opposed to 2 neutrons in Helium 4. Helium-3 fusion reactions have long been investigated because they do not produce energetic neutrons *[7]*. Only protons are released, which can be contained easily by electrostatic means, which can also be used to convert the energy of the protons into a useful form *[18].* For this reason, Helium-3 fusion cycles have very high efficiencies of more than 70% *[2]*.

One possible fusion reaction would be between Helium 3 and Deuterium (D-He3 fusion). This reaction has a stable product and does not produce any neutrons which could cause damage or activation. However, some of the Deuterium ions will also fuse in the reactor, which will lead to the creation of a limited amount of energetic neutrons through the D-D reaction described earlier. So this fusion reaction would greatly reduce the neutron problem, but it would not solve it, and would still lead to some radioactive products *[7]*.

To ultimately solve the problem of nuclear waste, the fusion of Helium-3 with Helium-3 would need to be utilized. The He3-He3 reaction does not produce any neutrons, which means that it does not create any radioactive waste, making it the safest and cleanest possible nuclear reaction.

The superiority of the He3-He3 fusion cycle becomes most clear if one compares the amount of energy released in the form of neutrons in the four fusion cycles, and therefore the energy which causes harm to the reactor and the environment: In D-T fusion it is 80%, in D-D it is 35%, in D-He3 1-5% and in He3-He3 0%. He3-He3 is the perfect fusion cycle *[7]* and would usher a new age of clean, safe nuclear energy.

4. Problems with Helium 3 Fusion

Despite its tremendous advantages, Helium-3 Fusion in the past has largely been ignored as a potential means for energy generation. As has been laid out by Professor E.N. Cameron and Professor G.L. Kulcinsky in their 1992 publication "*Net Environmental Aspects of Helium-3 Mining-Phase1: Effect on the Moon"* *[19]*, there are two main problems with the concept: The vast energy requirements for the fusion of these elements and the limited availability of the fuel.

4.1. Energy requirements

As mentioned earlier, a major issue for fusion power in general is overcoming the Coulomb barrier, so the most "fusable" elements are those with the smallest electrostatic repulsion. Helium nuclei carry two positive charges, as opposed to the one charge on Deuterium and Tritium nuclei. This means that much larger energies are required to bring Helium nuclei sufficiently close to each other to initiate fusion. The energies which a D-He3 reactor needs to operate are about 3 times larger than those needed for a D-T reactor. A He3-He3 reactor needs energies that are another order of magnitude higher *[7]*.

4.2. Availability

A massive problem which needs to be solved to achieve Helium-3 fusion is the extremely sparse amount of the isotope available on Earth. This was the reason why for long time the idea of Helium-3 fusion was unthinkable. In 1986, it was hypothesized that the surface of the Moon might contain large amounts of Helium-3 carried over from the sun over the past billions of years *[19].* Analyses of the lunar surface confirmed this hypothesis. This did not solve the problem of availability of the Helium, but it gave an idea of the direction into which humankind should be heading if it aims to utilize Helium-3 as a fuel for the future: Space.

5. Helium 3 in Space

5.1. Moon

The easiest and currently most realistic extraterrestrial source for Helium-3 is the Moon, where the Helium is found in the lunar "regolith". The regolith, or moon-dust, is a layer of fine-grained debris, which covers the lunar surface from about 5 to 10 meter depth *[20]*. It has been formed as a result of impacts of smaller bodies on the moon over the past billions of years *[23]*. Over that time, Hydrogen and Helium atoms from the Sun, among them Helium-3, have been carried to the moon by the solar wind and have been implanted into the regolith as it formed *[21]*.

A major technical issue is harvesting the Helium-3 and sending it back to the Earth, however, technical models have been invented which could solve that problem *[22]*: First, the solar gases would need to be extracted from the regolith. To achieve this, the regolith would need to be filtered for particles of less than 100 microns in diameter, as those contain the highest concentration of the gases. The gases would then be extracted by heating the moon-dust to temperatures of about 700°C, by using solar energy, for example. The regolith can then be returned to the surface of the moon. In order to separate the Helium from the other gases, the gases would simply have to be exposed to outer space during the lunar night. The low temperatures (below 5 K) would cause everything except the Helium to condense. The final task would be to separate the Helium 3 from the Helium 4. This can be done by various techniques of isotope separation. As the separation would take place on the moon, the most useful technique would be the “superleak” technique *[23]*, as it works regardless of the gravitational field. That technique makes use of the fact that at certain temperatures, He-4 is a superfluid while He-3 is a normal fluid. A filter with very fine pores is used, which allows only the superfluid He-4 to flow through, separating the two isotopes.

There are 10^9 kg Helium-3 in the lunar regolith *[24]*. The energy which it contains is more than an order of magnitude larger than the energy contained in all coal, oil and natural gas resources on earth *[25]*. If this Helium-3 will be utilized as a source of energy, it could make the Moon a more important source of energy in the future than the Persian Gulf is now *[18]*, radically changing the importance of Space in economic affairs on Earth.

5.2. Gas Giants

Obtaining Helium-3 from the solar system’s gas giants is a much harder task than mining the lunar surface. However, if it were possible, it would open up completely new frontiers in terms of the amounts of energy which could be produced. The atmosphere of Jupiter alone contains 10^{23} kg *[24]* of Helium 3. If mankind will become capable of harvesting this energy, it will secure its energy needs for the indefinite future. Different models have been proposed on how the Helium could be harvested from the atmosphere of the gas giants, the main ones being *Aerostats*, *Scoopers* and *Cruisers [26]*. *Aerostats* are buoyant balloons which would remain stationary within the atmosphere of a gas giant, thereby processing it to obtain the Helium. Other vehicles may be used to collect the harvested gases and bring them either to the orbit or to one of the planet’s moons. *Scoopers* are vehicles which would enter the atmosphere for a short time, “scooping” some amount of the gas, and then returning back to orbit. *Cruisers* are aircraft which would remain permanently inside the atmosphere, gathering the gases during their course. Other vehicles could be used to collect the gases from the cruiser and return to orbit.

6. Perspectives

The amount of usable energy contained in gas giant He-3 is so tremendous that it doubtlessly would find other uses apart from sustaining mankind’s energy needs on Earth. In 1973, the British Interplanetary Society proposed the “*Daedalus Starship*” *[27]*, a hypothetical interstellar unmanned spacecraft which was meant to harvest Helium-3 from Jupiter’s atmosphere and use it to travel a distance of 5.9 light-years to Bernard’s star within 50 years *[28].* This may be just a glimpse of the possibilities which those energy reserves could offer. One should keep in mind that the *Daedalus* spacecraft was based on technologies known in the 1970s. If mankind will set itself the goal to mine the gas giants of the solar system, there is no doubt that that would involve massive leaps in current space-flight technology. That, combined with the vast energy resources involved would lead to completely fantastic possibilities.

7. Conclusion

The utilization of Helium-3 fusion will be a major breakthrough for humanity. It will lead to reactors of yet unprecedented power and efficiency, and is a chief contender to solve the energy crisis in the 21 century. Being an entirely clean reaction, it will radically change the public perception of nuclear power. Mining the fuel on the moon will make the domain of Space an essential part of economic affairs on Earth. The tremendous amounts of energy contained in the Helium on the gas giants of the solar system will open up new frontiers for humanity on Earth and beyond. Mining those areas and utilizing the unlimited supply of energy may seem fantastic at the moment, but mankind will realize those possibilities. If we remember which things seemed fantastic at the beginning of the twentieth century and now are part of our everyday lives, it becomes clear that human progress does not have limits and will reach completely unimaginable heights in the future.

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