Humanity and Space

An Interactive Qualifying Project
Submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the
Degree of Bachelor of Science

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March 2022

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1 Abstract

The 21st century will be characterized by the upcoming energy and climate crises. There is a current theoretical discourse into the implementation of lunar helium-3 as the main source of nuclear fusion energy. Our team has investigated utilizing fusion on the moon to alleviate the energy crisis through the following vectors: maintenance of human presence on the moon; operation of helium-3 excavation; transmission of energy from the lunar surface to Earth; and conversion of the LASER power into electricity.

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2 Executive Summary

In this project, we explore the feasibility and address the challenges of utilizing helium-3 as a long term energy source to satisfy humanity energy needs. This involves transportation of humans and robots to the lunar surface, providing the means of extended protection from space weather, as well as adequate life support systems. Another issue to be addressed is the high frequency radiation that is very difficult to shield and can cause permanent DNA damage. The location of the lunar outpost must be decided based on access to energy, ease of travel, communication capabilities, environmental factors, and the proximity to helium-3. Robotic systems must also be designed and implemented to perform a large-scale mining operation without the constant need for maintenance or support. The helium-3 must then be efficiently and cleanly converted to energy. The main proposal of our team is to use well-established LASER technologies for the purposes of the energy transmission through the 252,700 miles that separate the Earth and the Moon. The issues of the laser going through the atmosphere are addressed using the classic topics of Rayleigh Scattering, turbulence of the atmosphere, and interaction between the light and molecular bonds of the gases that compose the atmosphere. The last part of the project has been devoted to the research of the modern technologies designed for conversion of the highly coherent light into the easier to use forms of energy, such as electricity.

3 About the authors

3.1 Tammie Zhu

I decided to complete this IQP because I wanted to learn more about something outside of my academic discipline. The supply of natural resources, specifically those from non-renewable sources, are being rapidly depleted, and it is important for humanity to find other sources of energy. One potential source of energy that is being highly researched is that of helium-3, an isotope of helium that is abundant on the moon. There are also challenges in regards to the genetic and biological aspects of space travel. Space travel has many challenges on the biological front, such as protection against ionising radiation, that must be considered when astronauts travel in space for long periods of time. This project allowed me to explore many different possible avenues of dealing with the problems: from studying the already established ways of protecting against space weather to looking into the ways that certain micro organisms utilize their specific structure to minimize the adverse effects.

3.2 Daniil Volkov

My main motivation behind participating in this project is that it is the perfect opportunity for me to combine my undergraduate experience with mathematics and physics to work on one of the most promising areas of research today. It has been clear since the 1980s that in order for humanity to progress we will have to eventually trespass the very finite and rapidly decreasing resources of Earth. Since the collapse of the Soviet Union, the space race has severely slowed down, but I believe that we are at the very start of its next stage. Helium-3 mining could be that perfect starting case that is both valuable enough and impossible to get on Earth to kick off the space excavation procedures. This very much fits within the realms of the science fiction that I used to read as a child. Overall, doing the work for this project felt very similar to looking for real technologies to fulfill the dreams of Izaak Asimov while looking for solutions to the most real problem there is.

3.3 William Luksha

I decided to do the Humanity and Space IQP because I want to see technology developed to benefit humanity. Lunar helium-3 fusion has the ability to alleviate the current energy crisis, and researching the needed technology and logistics to enable such an operation fits well within my physics studies. Since I have spent time examining several areas of physics, it enabled me to look into a variety of topics and gain an overall understanding of the many topics presented in this project.

3.4 Yonglong Zhan

My motivation for this IQP comes from my interest in research of alternative energy sources. Today, a lot of great countries, such as China and European Union, pursue the concept of zero-emission initiative, which led to the rise of solar energy, hydrogen energy, and wind energy. However, they are simply not sufficient for humanity's raising energy demand. With the quantum background I have built up at WPI, I had the proper background to understand the technical details of projects, such as the Quantum Dot Solar Cell. That became very useful as I was working through the research papers on the topic of conversion of the laser into more accessible forms of energy.

3.5 Leo Zhu

My motivation for this project comes from my interest in both space and biochemistry. This project allowed me to understand what has not yet been done in these fields and allowed me to broaden my views. The concept of space travel has also become a lot more prevalent in recent years where even some private companies are looking for opportunities to get in, but currently, there are many issues with health risks when it comes to human space travel. This was a great experience because it allowed me to think of ways to apply my biochemistry background in finding solutions to DNA damage.

4 Introduction

Since the 1957 when the Soviet Union has sent the first artificial satellite *Sputnik 1* into orbit, there has been an active discussion amongst the academics as well as government officials about utilizing the extraterrestrial resources for the betterment of life on Earth. Right now the most current evolution of this debate is the use of helium-3 for the fusion reaction. In the context of the perpetually worsening energy crisis, compounded with the degradation of the ecosphere, the ecofriendly method of energy production became extremely appealing. In this report we have divided our attention to answering a series of questions that are crucial if the project is ever successful.

When the first astronauts were sent to space, there were many issues that became apparent during the long missions. Astronauts are essential to maintaining space equipment and systems; therefore, it is important to keep them healthy while they are in space. Space has a completely different environment compared to Earth. Life on Earth is protected by the atmosphere and the magnetic shield, whereas outer space, such as the Van Allen Belts, is unfit for human life. An unprotected human being would experience extreme temperature changes, radiation, and other extreme conditions. Even with modern space suits, there is still an array of possible problems. Some of these complications include muscle and bone atrophy as well as cardiovascular concerns. Many of the issues resulting from microgravity have been solved over the years; however, radiation is still an issue that has yet to be completely solved. Although extremely rare, complications from radiation include increased risks of cancer and heart issues. Some solutions have been proposed in this paper to counteract the potential DNA breakages that can result from certain types of radiation.

To make the main objective of using helium-3 as fuel for fusion, it will require a large-scale excavation effort. This will need to be largely if not completely autonomous, as resupply missions are costly. This will involve thousands of robots to excavate, refine, and transport material to a determined drop-off point. The location of the helium-3 must be determined and the technology used must be compatible with the lunar surface conditions. The next part of the project is to convert helium-3 into the fusion energy and then send it towards Earth's needs.

One of the more fun approaches that is considered in this paper is to cut down on the transportation cost of helium-3 from the lunar surface to Earth and instead utilize it at the excavation sight using a fusion reactor on the moon. Even though it does sound very much like science-fiction, there are already technologies that allow us to use fission reactors, a cousin of fusion, that are fairly small, such as small modular reactors. That brings up the question of transporting the energy back to Earth, and our team has investigated the possibility of using LASERS for that purpose going fairly in depth. It turns out that even though the power that we would be operating with would be fairly difficult to contain, there are some ways to work around it.

The final part of the concept would be for the laser to go through the atmosphere where the power would be captured using the modern applications of advanced solar cells. All such devices utilize specific band-gaps of different materials that allows the electrons to get excited and therefore easily separate from the molecules allowing for electricity. The flaw in commercial solar cells today is the loss in conversion, and there are multiple ways to bypass the limitation by using Quantum dots technology or Multi-Junction solar cells.

5 Human Space Travel

When considering human space travel, astronaut safety is of the utmost importance. There are multiple biological hazards that must be considered when sending astronauts to space for long periods of time. Not only are there immediate dangers, such as the vast temperature differences, there are also subtle dangers that take time to manifest. For instance, due to low gravity, many astronauts face muscle and bone atrophy unless they are preemptively prevented. These dangers are not immediately present until astronauts return to Earth where gravity is present, and the months of being in a low gravity environment begin taking a toll on their bodies. Although these problems feel daunting at first, they are treatable and preventable with the right nutrition and exercise while astronauts are in space.

There is another problem; however, that is harder to solve: space radiation. In this chapter, the main focus will be to study the cause of space radiation, the biological consequences, and possible solutions. Later in the chapter, when considering biological solutions, particularly those that include gene editing, it is important to note that these ideas and solutions are theoretical, and before any further research or experimentation, it is important to keep in mind not only biological limitations, but also ethical considerations.

5.1 Space Weather

The environment on the moon is rather dangerous. Not only does the moon not have a magnetic field to deflect charged particles, but the surface of the moon is also covered by fine dust made up of silicon dioxide crystals [42]. These crystals are harmful to both humans and equipment. Gravity on the Moon is much weaker compared to gravity on Earth. Due to the Moon's low gravitational field, these dust particles, when disturbed, are lifted off the surface higher and longer compared to on Earth. These particles attach to space equipment and irritate astronauts' eyes, nose, and lungs [42]. These particles are also called lunar dust and contain silicate. Although extremely small (50 times smaller than human hair, approximately 0.3mm as seen in Figure 1) these particles were, in fact, extremely abrasive and were able to grind down layers on an astronaut's space suit [8]. The particles are extremely sharp, similar to glass, and are able to easily enter and stay in an astronaut's lungs. Long term exposure to these particles can be extremely dangerous, because having entered astronaut's body they are even capable of to destroying brain cells. As there is no atmosphere on the Moon, lunar dust is never filed down and particles remain sharp [8].

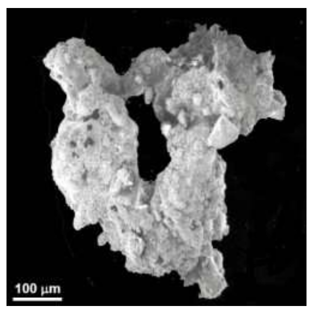

Figure 1: A lunar dust particle at 100 100µm magnification [11].

There are also extreme temperature variations on the Moon. Temperatures can reach as high as 127°C and as low as -173°C. Space suits must be able to insulate the astronaut sufficiently with these extreme temperature changes [42].

5.2 Muscle and Bone Atrophy

Space is a microgravity environment, and many biological problems arise due to this. A well known issue from microgravity is bone loss and kidney stones. This is because bones play a crucial role in structure and support on Earth. Bones are constantly reshaped through a delicate balance of re-absorption and formation [19]. In a microgravity environment, astronauts do not experience the same pressure as they do on Earth. This lack of stimuli results in increased bone resorption which in turn leads to decreased bone formation. This results in bone mass loss at a rate of approximately ten times that of osteoporosis. For instance, the proximal femoral bone loses roughly 10% over a six month period in space. This loss can take three to four years to recover. The calcium balance is the difference between calcium intake and excretion. On Earth, the calcium balance is roughly zero, however on space, the calcium balance is -250mg/day during flight. This value indicates an increased risk for kidney stones. With the help of weekly bisphosphonate intake, as well as sufficient nutrients, exercise, and minimal medication, astronauts are able to prevent this bone loss [19].

Along with bone atrophy, muscle atrophy was also a concern. In the absence of gravity, work is physically undemanding. On Earth, muscles are frequently used to do daily work as well as support the body from collapsing. These muscles are often called antigravity muscles and include muscles like the calf, quadriceps, back, and neck muscles. On space flights that last five to ten days, astronauts can experience up to 20% muscle mass loss [3]. This large percentage of muscle mass loss is dangerous when astronauts re-enter Earth's gravitational field. The only way to combat this muscle mass loss is through intense exercise. For instance, astronauts on the International Space Station must spend 2.5 hours per day exercising as a counteractive measure [3]. Skeletal muscles, however, are known for their plasticity, and astronauts are able to regain their strengths once they begin training back on Earth [4]. The danger lies in longer space flight durations, where astronauts may spend months in space. In those scenarios, it is utmost important that astronauts do not slack on proper exercise and nutritional diet.

There are also other cardiovascular concerns. The human cardiovascular system was evolved to adapt to Earth's conditions. Once astronauts leave Earth's gravitational field and enter space's microgravity environment, blood no longer flows the same way. Blood and other bodily fluids are pushed from the legs towards the heart and head [45]. This shift causes decreased blood in the heart and blood vessels while increased swelling of the face. There are both long and short term effects to these cardiovascular changes. The fluid shift not only affects the cardiovascular system, but also the brain, eyes, and other neurological functions. The increased fluid to the head causes brian pressure that can lead to hearing loss, brain edema, and deformation of the eye known as Spaceflight Associated Neuro-ocular Syndrome (SANS) [45]. The heart also requires less work to pump blood in space, thus astronauts' hearts become more spherical and lose muscle mass (Figure 2) [62]. Once astronauts return to Earth, some experience orthostatic intolerance: difficulty/inability to stand due to lightheadedness and/or fainting.

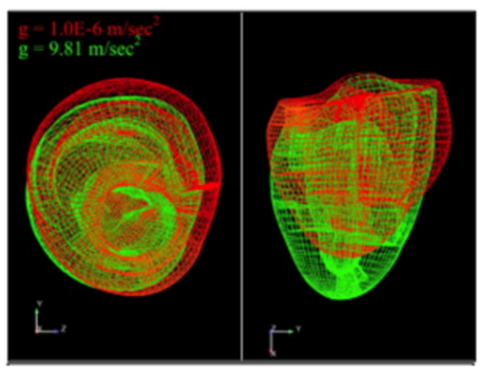

Figure 2: The predicted change of the heart shape when on Earth (green) to when in a microgravity environment (red) - credit to Dr. Chris May [62].

It was found that astronauts on the International Space Station had hearts that were 9.4% more spherical while in space and followed the mathematical predictions seen in Figure 2 [62]. The spherical shape could mean that the heart is functioning less efficiently, but it appears that the condition is only temporary. Once the astronauts returned to Earth, their heart shapes returned to normal. It is unclear if there are any long term effects due to this shape change.

Despite the wide range of areas that microgravity impacts, this IQP will not continue further into the cardiovascular issues as well as muscle and bone atrophy. This is because, while these issues are a concern for astronauts in space for long periods of time, these issues can be mostly prevented through an intestine exercise regime and nutrition, as well as some supplemental nutritions. There are many exercise equipment, such as the Advanced Resistive Exercise Device (ARED), treadmills, and stationary bikes, that astronauts take advantage of when exercising. There are also special trousers that use pressure differences to pull blood back into the abdomen and legs [45]. As many of these issues are preventable and treatable, this IQP will instead focus on aspects of biological space safety that, as of yet, does not have a completely preventable and treatable solution—radiation.

5.3 Space Radiation

The most concerning aspect of human space travel is the natural radiation environment emitted by deep space. This includes solar energetic particles (SEPs), galactic cosmic rays (GCRs), and micrometeorite bombardments. The radiation intensity of the environment also varies with correlation to the distance from the earth due to the earth's magnetic field, where low Earth orbit (LEO) will experience lower levels of radiation. The further we leave Earth's vicinity, the less shielding we receive, resulting in much higher SEP and GCR exposure. Another concern is the Van Allen belts that are formed due to the Earth's magnetic field. These belts are composed of different materials, most of which are radioactive particles originating from the solar wind.

SEPs are much more dangerous to astronauts in comparison to other electromagnetic radiation. SEPs consist of 95% protons that have been accelerated during

Solar particle events, such as solar winds, solar flares, and coronal mass ejections. SEPs have the ability to damage control systems and solar cells of satellites by traveling through a planet's van Allen belts. The energized SEP protons can also ionize cellular components, damage and destroy DNA, and at higher exposure levels, even kill cells and cause irreversible organ damage. Because SEPs can be easily shielded, they tend to have a lower impact, however, there are occasional SEP events in the solar cycle that would expose astronauts to radiation levels far above the allowable amount.

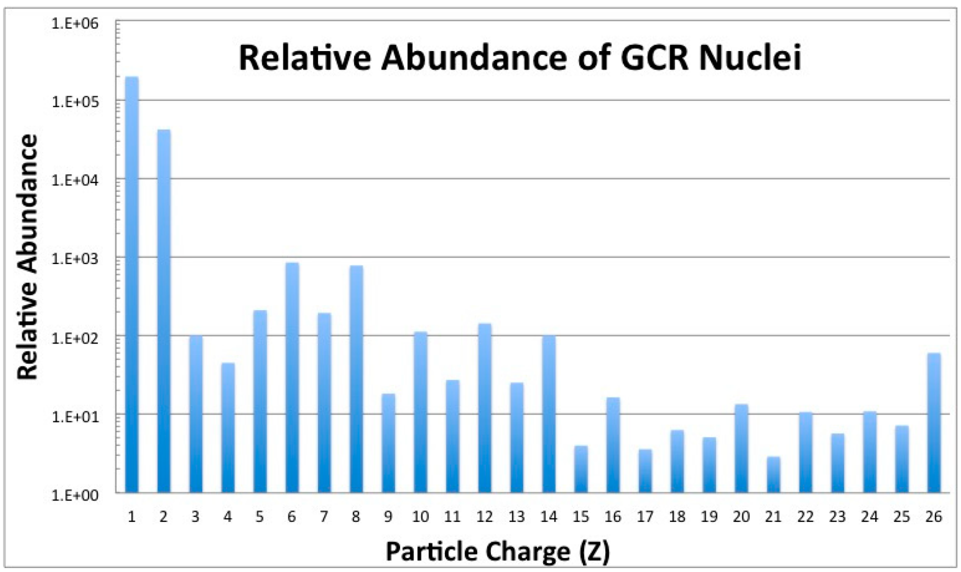

Figure 3: The relative abundance of GCR nuclei (protons) from hydrogen (Z=1) to iron (Z=26)[21].

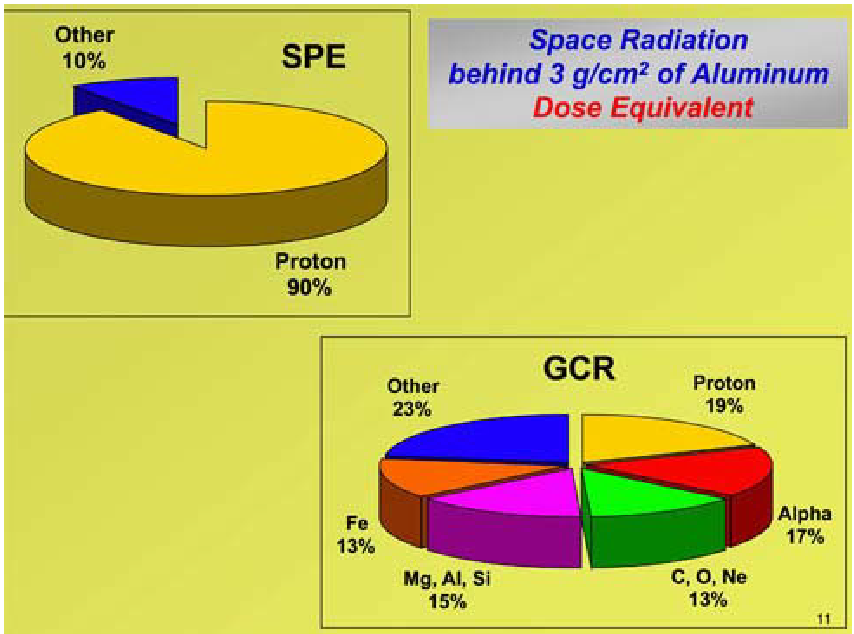

Figure 4: Relative contribution of different components of SPE and GCR to dose equivalence [66].

The most dangerous type of space radiation would be GCRs. Arising from distant supernova explosions, they are composed of mostly charged protons. Unlike SEPs, GCRs tend to have much higher energy, up to four orders higher than SEPs, but come in lower fluxes in comparison. GCRs are approximately 87% hydrogen ions (a single proton), 12% helium ions (alpha particles), and 1-2% high atomic number and energy (HZE) nuclei [66]. In reference to Figure 3, HZEs would refer to all of the particle charges from Z=3 to Z=26. Ionized transition metals (Z=22+ in Figure 3) are the most biologically harmful. Out of all the GCR radiation, the 1-2% HZE ions are the most harmful, contributing to over half of the radiation dose equivalent, and are difficult to avoid (Figure 4). With increasing expedition durations, the long-term risks of GCR radiation exposure will greatly increase. These effects include cancer mortality as well as cell damage in the heart, brain, and lenses of the eye. They release electrons while the densely ionizing track is capable of penetrating deep into tissues. Because SEPs can be blocked more easily than GCRs, the best time for missions would be during solar maximums, where the sun's magnetic field becomes stronger, blocking more GCRs but increasing SEPs.

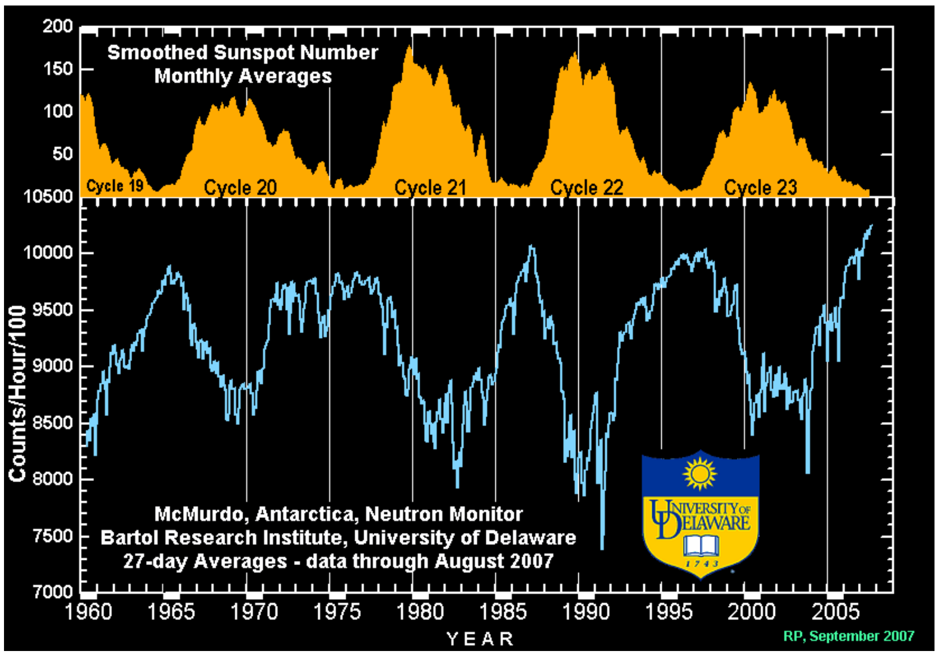

Figure 5: A graph displaying the flux of SPEs and GCR exposure since 1960 at the Mcmurdo Station, Antarctica [2].

The flux of SEPs and GCRs are not constant and repeat on cycles that are determined by the phase of the solar cycle. The solar cycle repeats on an 11 year cycle, alternating between solar maximums and solar minimums determined by the strength of the sun's magnetic field. During maximums, the field grows stronger and produces more SEP exposure while during minimums the field weakens, resulting in less SEP exposure (Figure 5)[2]. GCR flux is also on this cycle but just completely out of phase because that the Sun's magnetic field deflects GCR radiation due to GCRs being positively charged.[46] Thus, an expedition during solar maximums would result in a lower GCR exposure at the cost of increasing SEP exposure, and vice versa with solar minimums.

5.4 Some Concerns Regarding Space Radiation and HZEs

Ionizing radiation causes DNA double stranded breaks (DSBs), which are the most hazardous types of DNA breaks due to the lower fidelity in DNA repair. This is especially true when it comes to GCR, specifically the flux of HZE ion composition of the GCR. HZE ions have high-Linear energy transfer (LET) pathways, meaning that the path of ionization is dense and concentrated, creating complex DNA lesions where multiple DSBs can occur, resulting in significantly lower fidelity during DNA repair.[69] While in space, every cell nucleus will be traversed by a hydrogen ion every few days and a heavier HZE ion (high energy and charge) every few months. These GCR particle energies are capable of penetrating multiple centimeters of human tissue/organic and inorganic material, reducing shielding effectiveness due to the penetrating power of HZE ions. Thicker shielding would provide more protection, however, is impractical due to weight constrictions.

Radiation can also cause health problems by damaging the crew's equipment and supplies. As mentioned previously, the GCRs and SEPs will ionize molecules in it's path and can damage and ionize the molecules in its path. Radiosensitive medications are susceptible to this, and the active pharmaceutical ingredient (API) can be damaged so that it loses its potency and can even degrade into toxic compounds. Over time, cumulative radiation exposure will render those types of medication ineffective which will impose a huge health risk on the crew due to lack of effective medication[20].

5.5 Chromosomes

A living organisms' genetic blueprint is encoded into their DNA. For eukaryotes (multi-celled organisms), this DNA is coiled up into chromosomes, an evolution from prokaryotes (single-celled organisms) which only have a single, circular, and looped chromosome. Eukaryotes evolved from prokaryotes. Logically, if an organism had more chromosomes, there would be more genes, and that would make the organism more complex; however, this is not always the case. This leads to the question, is there a correlation between an organism's complexity and its chromosome numbers? The answer is, not exactly.

Although indeed, as eukaryotes have evolved from prokaryotes, eukaryotes have more chromosomes and are much more complex. Despite this, there is also a great variation in chromosome numbers between different eukaryotic species. For example, some outliers include the crayfish and field horsetail, both of which have more than 200 chromosome pairs (Table 1) [64]. Dogs and chickens also have more chromosomes compared to humans (Table 1), but it is clear that humans are more complex than dogs and chickens.

Table 1: The diploid numbers of commonly studied organisms along with some extremes [64].

Homo sapiens (human)	46
Mus musculus (house mouse)	40
Drosophila melanogaster (fruit fly)	8
Caenorhabditis elegans (microscopic roundworm)	12
Saccharomyces cerevisiae (budding yeast)	32
Arabidopsis thaliana (plant in the mustard family)	10
Xenopus laevis (South African clawed frog)	36
Canis familiaris (domestic dog)	78
Gallus gallus (chicken)	78
Zea mays (corn or maize)	20
Muntiacus reevesi (the Chinese muntjac, a deer)	23
Muntiacus muntijac (its Indian cousin)	6
Myrmecia pilosula (an ant)	2
Parascaris equorum var. univalens (parasitic roundworm)	2
Cambarus clarkii (a crayfish)	200
Equisetum arvense (field horsetail, a plant)	216

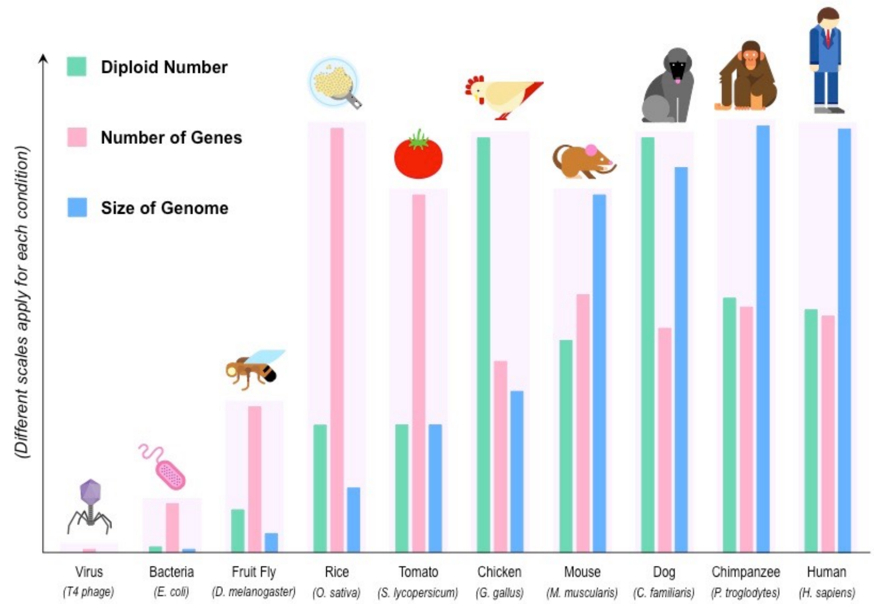

Figure 6: A comparison between chromosome number (green), genome size (blue), and gene count (pink) for various organisms [17].

Cells frequently undergo the cell cycle, and with each cell cycle and cell division comes mutations. Some mutations include double-break strands, duplication, deletions, inversions, translocations, etc. [35]. Oftentimes, these mutations are patched by the system in the cell, however, not all mutations are caught 100% of the time. Mutations which are not repaired or are mis-repaired continue to divide. If the mutation happens in the gamete cells, then the mutation will be passed onto future generations. It was most likely that there were chromosomal breakages early on when eukaryotes evolved from prokaryotes, and those mutations further divided into multiple other mutations which made certain species viable in certain environments and conditions. That would explain how dogs have more chromosomes than humans despite not being anymore complex or further along the evolutionary tree (Table 1). Some organisms, such as plants, can have large genome sizes because of their ability to self-fertilize become polyploid, and thus require more genes to fulfill that complex cycle (Figure 6) [18].

In conclusion, chromosome numbers do not indicate genetic complexity. Chromosomes come in various sizes and lengths. Not only that, but chromosomes also carry different genetic information, and ultimately it is the genetic information that each chromosome contains that determines the complexity of an organism.

5.6 Gene Therapy

The way to change an organism would be through its genetic information [26]. Scientists have already genetically modified organisms (GMOs) many times to get desirable gene expression and phenotypes (observable traits).

Gene therapy is an experimental technique in which a functional copy of a gene is inserted into a patient's genome in the hopes of treating a genetic disease. Although gene therapy has been traditionally used to treat genetic diseases in humans, gene therapy can also potentially be used to introduce new genes to the human genome—some which are resistant to radiation damage. Gene therapy can be applied at two levels: germ-line and somatic.

In germ-line gene therapy, the gene is inserted into a germ cell to provide a permanent gene sequence, as germ-line cells are reproductive cells, and any gene inserted would be passed down to the next generation. This technique has not yet been approved for humans, but it has been performed on other animals. In somatic gene therapy, non-germline tissue is treated so that the genome of the individual receives the gene but not the patient's following generations.

With somatic gene therapy, it could be possible to introduce a gene that promotes radiation resistance into certain cells or tissue. For instance, Deinococcus radiodurans is one of the most radiation resistant organisms known. If the specific gene responsible for D. radiodurans radiation resistance could be identified, then further testing could be conducted with the gene in human cells.

Scientists have not yet ethically performed genetic modification on the human embryo. Gene therapy, on the other hand, has been successfully performed on patients with debilitating diseases with no other cure. Gene therapy is a technique to modify a patient's genes to treat or cure their disease. This is performed either by replacing the disease causing gene with a healthy copy or inactivating a disease causing gene that is functioning improperly. In gene therapy, a gene is transferred into a cell through a vector. The most typical form of a vector would be viruses because of their innate ability and adaptability to invade a cell and deliver genes. Another vector that was discovered was CRISPR-Cas9, which is known for its ability to target specific sequences and make a precise cut to inactivate the gene.

An example of a successful gene therapy attempt would be one of the first trials of gene therapy approved by several regulatory committees to treat one type of Severe Combined Immunodeficiency (SCID). The Adenosine deaminase (ADA) gene produces the ADA protein, and a mutation in the ADA gene produces non-functional ADA protein. The result of this non-functional ADA protein results in SCID, a debilitating and fatal childhood immunodeficiency disease. The children with this disease have very weak immune systems which cannot fight off even the lightest infections, and thus have to live in sterile environments (such as the bubble boy). The first trial was performed on Ashanti DeSilva in 1990 with a retroviral vector, and she was successfully treated and was able to continue her normal life [16].

There has been some study on the application of gene therapy for radioprotection, particularly for cancer patients who undergo radiation therapy as treatment. Radiation therapy is a critical part of cancer treatment, but there are still risks of side effects of off-target radiation damage to normal tissues. To reduce normal tissue damage from this radiation, antioxidant genes can be delivered to increase detoxification of free radicals from radiation. Delivery of growth factor genes can also help damaged cells survive as well as delivery of transgenes to restore tissue function after radiation damage [32].

Although germ-line gene therapy would be more effective in giving all of the patient's cells the gene, there are possible off-target effects. These effects are unpredictable and it is possible that these unwanted genetic changes could be passed down, and as a result, have unprecedented consequences on future generations.

5.7 Synthetic Chromosome

There are multiple ways in which genetic information is delivered to cells for treatment. The genetic delivery vehicles that are currently available in the clinic for treatment of disorders do not have a large enough carrying capacity to carry many large gene sequences. A possible alternative to insertion of genes through vectors could be insertion of completely synthetic pairs of chromosomes, also known as mammalian artificial chromosomes [13]. In application to space safety of astronauts, these chromosomal pairs would contain genes to help with space radiation and produce proteins to help do so. When astronauts are in space, there are high chances of DNA breakage and damage from space radiation. Over several years, the amount of genetic information exchanged or added to cells has grown larger. Currently, the construction of entire chromosomes has become a reachable goal [26].

Synthetic chromosomes are a viable option for delivering large genetic loads that are independent from the host's own genome and are stable when cells undergo cell division. Synthetic chromosomes can be generated through four possible means. One of these methods involves transfer of different, defined chromosomal elements, such as the telomeres, mammalian replication origins, etc, along with a marker into a permissive cell line. The cell then assembles the different components into an artificial chromosome.

Although the idea of synthetic chromosomes are promising, there are many problems that must be addressed. Aneuploidy occurs when there is an abnormal number of chromosomes in a cell and is a distinguishing characteristic of cancer as well as other underlying genetic disorders [63]. The exact mechanism that causes this physiology is still unknown. Addition of even a single chromosome in a human cell promotes genomic instability by increasing DNA damage and sensitivity to replication stress. Replication stress was found to be one of the primary causes of genomic instability and one of the early stages to tumorigenesis, the gain of malignant properties in normal cells, and cancer. Trisomy (addition of single chromosome) and tetrasomy (addition of two chromosomes) was seen to cause genome-wide gene expression changes. One that was the most notable was the replication factors became reduced/suppressed, and therefore contributed to replication stress [63].

5.8 Chromosome Inactivation

There is a known mechanism in which the X chromosome is deactivated. This process is known as lyonization, or X-inactivation. In mammals, males are born with just one copy of the X chromosome, however, females are born with two copies of the X chromosome. With double the number of X chromosomes, females would be producing double the proteins in which the X chromosome encodes for. In reality, this does not occur due to the inactivation of one X chromosome. The inactivation occurs in permanent, irreversible chemical modifications [50]. This phenomenon can be physically seen in Calico cats, which are almost always female. The gene which encodes for the cat's fur color is located on the X chromosome, and depending on which X chromosome is deactivated, the phenotype of the fur is either black or orange (Figure 7) [34].

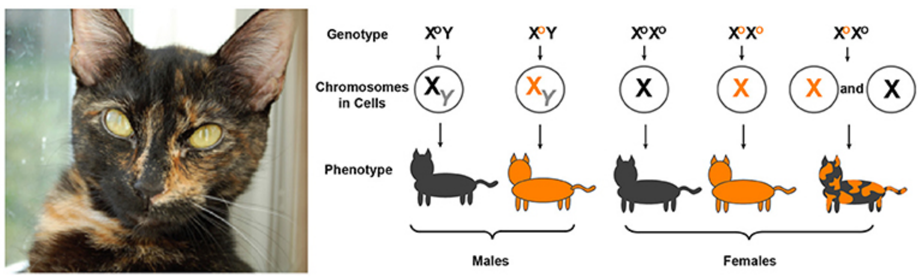

Figure 7: A diagram which illustrates how black and orange fur color genes are on separate X chromosomes, and how this would present phenotypically in males and females [59].

The deactivation of the X chromosome is random, but interestingly, in X-linked disease present in females, it is almost always the X chromosome which carries the disease which is inactivated [50]. The normal, non-abnormal copy of the X chromosome is left to be the functional, and the disease does not present phenotypically in the female. For example, this is why more human males are colorblind compared to human females, as the gene responsible for seeing color is present on the X chromosome. As males only receive on X chromosome, they do not undergo lyonization and present the phenotype of being colorblind.

With this concept in mind, it could be possible to create synthetic chromosomes which remain dormant in the body until needed. The synthetic chromosome, however, would have to be silenced through other chemicals not used in other cells. For instance, certain genes on chromosomes can either become activated or deactivated through methylation. It would be unwise to also use methylation as the same activation/deactivation mechanic for this synthetic chromosome. Dormant synthetic chromosomes have a chance of being viable in which the original chromosome is damaged due to radiation particles, it can be deactivated and the dormant synthetic chromosome can be activated and act in its stead. This idea is a far stretch as there are many nuances that come with this concept. For example, how would the exact chromosome that is damaged be identified, and how would this treatment be executed? The synthetic chromosomes would have to be somehow transported to every cell, and the cell would have to have the ability to somehow hold these synthetic chromosomes in the nucleus, which is already packed with the original chromosomes.

5.9 Solutions to deleterious DNA repair

5.9.1 Discovering and creating new biological solutions

Discovering radioprotective methods needs to be further studied because they have the potential to negate deleterious effects that can cause lethal events through errors and base excision. Ways to further study and discover organisms that have higher tolerances to ionizing radiation may be found in species residing in Chernobyl where the less radiosensitive species tend to do better. Another possibility can be found in HeLa cells, a line of immortalized human cancer cells. It may be possible to selectively culture HeLa cells and expose them to high LET radiation at the NASA Space Radiation Laboratory (NSRL), where they have developed a GCR simulation machine that produces spectrums of ion beams to match the GCR composition[61]. This could induce the development of a pathway where lethal events can be prevented. These methods would only produce a potential radioprotective pathway, however, it is not guaranteed that they will prove to be effective in humans and against GCR, due to possible incompatibility with humans and capability against high-LET radiation respectively.

In recent years, there has been promising research on a protein, Dsup, in tardigrades that acts as a tumor suppressor by protecting DNA from ROS compounds[67]. This has been applied to human DNA and has proven to act as a radioprotector, however, the research is still in progress as researchers do not know how Dsup operates in humans and the systemic risks that come from the addition of Dsup to the cell. Further research on extremotolerant organisms like these may give rise to more options for radioprotective genes like Dsup that can be adapted into our radioprotective genes, protecting us from space radiation. [36]

5.9.2 Using Chromatin Templates to Preserve DNA

One potential method of approach at reducing the rate of disease caused by high-LET radiation is by targeting the type of DNA repair the cell uses to repair DSBs. In human cells, two pathways for repairing DSBs are known as non-homologous end joining (NHEJ) and Homology directed repair (HDR). When a homologous strand of DNA is present, HDR will take place and the pathway will use it as a template to repair the DSB with high fidelity, however, when the homologous strand of DNA is not present, the cell will turn to a more error-prone method, NHEJ and it may result in loss of nucleotides (Figure 8). NHEJ is the most common and simplest repair pathway since it does not require a template for accuracy and is described as a 'duct tape' method for repair, while HDR usually only occurs during specific parts of the cell's reproduction phases and repairs to much greater accuracy.

The article discusses methods to increase the precision of genome editing by attempting to make the HDR process more efficient.[30] By transfusing the cell

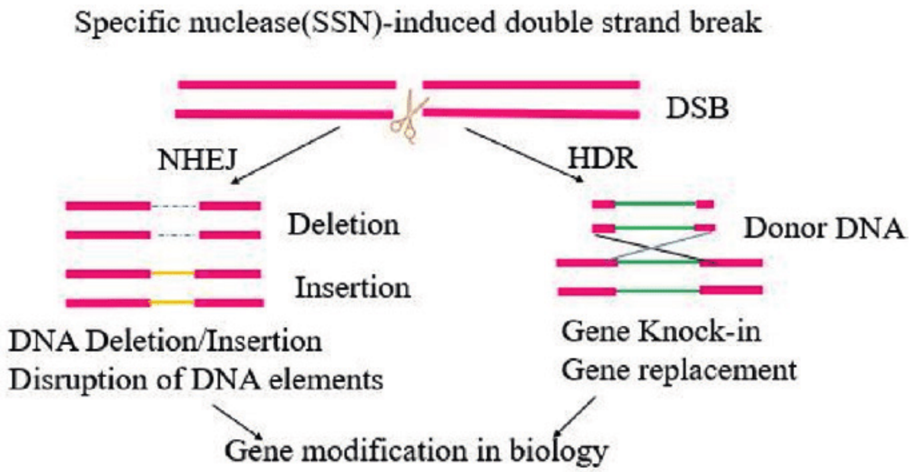

Figure 8: Displays the ways that NHEJ and HDR repairs DSBs. NHEJ reduces the DSB by removing ends and then joins the two strands. HDR utilizes a Donor DNA template to accurately repair the sequence without deletion [68].

with chromatin based DNA template, they were able to induce an increase in HDR efficiency by a 2.3 to 7.4 fold increase.

After exposure to high-LET radiation, the main concern is the error rate of the DSB repair that follows. Being able to reduce the rate of DSB repair deletions through a chromatin template that increases HDR rates may have some potential applications directly in human cells.[22] Similar to the addition of an inactive chromosome to provide the cell with a working function copy of the gene, this would work similarly to produce an accurate copy of the gene as a template. If the most oncogenic areas of our genome can be determined, then we could create a chromatin donor template of that segment and distribute it to organs that tend to have a higher risk for cancer. This would reduce the rate of NHEJ by promoting HDR to reduce the rate of DSB repair errors. However, the current questions that are left unsolved include how this can even be administered, as it is likely not possible to administer to all cells. But this does leave a potential angle to take on the problem if there is a way to induce a higher rate of HDR for DSBs in human cells. One potential solution is the use of gene therapy to induce the creation of template chromatin to make repair errors less frequent. This method could also be targeted towards especially susceptible oncogenic organs.

5.9.3 Effects of high-LET radiation on cellular pathway NHEJ DSB repair

Another cause of the low fidelity in DSB repair is due to the NHEJ pathway and the proteins involved. When a human cell line is exposed to high-LET radiation and then enzymatically induced DSBs are created, the repair process after radiation usually leads to 12-20 nucleotide deletions. The two NHEJ pathways that were responsible for the repair of the DSBs were canonical-NHEJ (c-NHEJ) and alternative-NHEJ (alt-NHEJ) pathways. C-NHEJ is a very efficient pathway at repairing DSBs but may result in the deletion of just a few nucleotides, while alt-NHEJ tends to result in large deletions of the DNA, suggesting that alt-NHEJ was the cause of the deletions during repair.[69][52] The reduced rate c-NHEJ repair is due to the high-LET radiation inhibiting the Ku protein that is responsible for c-NHEJ DSB repair.[33] It is theorized that high-LET radiation causes the inhibition because the free DNA fragments that are created compete with the site that needs the Ku protein. Because of the reduced levels of Ku protein, the cell takes the alternative pathway, alt-NHEJ, resulting in much larger deletions and creating a much greater risk for genome instability.

Because of this, Ku protein could be a potential target for improving fidelity, as it would increase the rate of repair dependent on Ku. By upregulating the Ku proteins through gene therapy or drug supplements, there could be potential at reducing the impact that high-LET radiation has on the human body. If the frequency of c-NHEJ does not get compromised by the high-LET radiation, then the highly deleterious effects of alt-NHEJ should be expressed less frequently, leading to a smaller chance of genomic instability and disease.

5.9.4 Applying Deinococcus Radiodurans Radioprotective Methods

Another source of potential solutions could be derived from Deinococcus Radiodurans, which is a species of bacteria well known for their capability to survive high levels of ionizing radiation environments. D. Radiodurans have some mechanisms that contribute to its ability to survive ionizing radiation and some of these methods could potentially be used in humans to mimic the way D. Radiodurans preserve their DNA fidelity.

One resistive property of D. Radiodurans is their high antioxidant activities, allowing quick reduction of the reactive oxygen species (ROS) caused by ionizing radiation that in turn produce DNA strand breaks. This method could be applied in humans through drugs, however, this method would prove to not be effective against high-LET based breakages since high-LET radiation can directly ionize the DNA to cause breakage and does not require a ROS mediator. D. Radiodurans also have a homologue of the eukaryotic RAD52 protein called DdrA, which is how eukaryotes use NHEJ to repair DSBs. They also possess the protein RecA, which is a homologous DNA repair protein, resulting in higher fidelity during DNA repair.[43] This could have the potential to prove useful in human DNA repair through gene therapy to produce greater fidelity during DSB repair, however, there will be many complications due to the sensitivity and incompatibility.

The most interesting way D. Radiodurans protect their DNA fidelity is through the way their DNA is stored. Research suggests that they have a highly condensed nucleoid due to the high cation composition that helps reduce the phosphate repulsion within the DNA, allowing for a more condensed structure. With a more condensed nucleoid, DSB breaks will diffuse at a slower rate, and the free floating

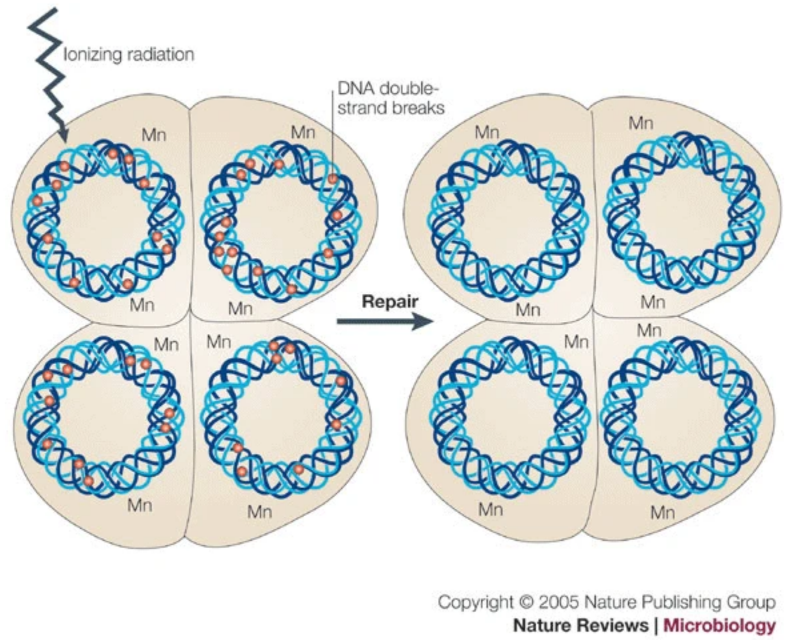

Figure 9: Displays highly condensed nucleoid and repair process of D. Radiodurans [43].

DSB fragments caused by the ionizing radiation will be reduced (Figure 9). If this property of D. Radiodurans is able to be reproduced inside human cells, that would theoretically reduce the rate at which Ku proteins will bind to free floating inhibitory DSB fragments that compete and exhaust the concentration of Ku protein that is available for actual NHEJ DSB repair.

Many problems arise when applying this to human chromatin or any eukaryotic chromatin however, since eukaryotic DNA and prokaryotic DNA are fundamentally stored differently, where prokaryotes lack the histones to bind up DNA that eukaryotes use to bind DNA. Prokaryotes instead have a singular chromosome that is condensed into supercoils. If this method to preserve human DNA fidelity sees further research, the direction that this would go would likely not be based completely on the way D. Radiodurans condenses its chromosome due to the fundamental differences. What can be considered is how D. Radiodurans can highly condense the chromosome to reduce the amount of DSB fragments. Condensing the human chromatin would see many issues as well, due to the uncertainty of the safety of this, however if research proves this to be possible, this would provide astronauts with a much higher resistance against high-LET radiation.

5.10 Passive and Active Shielding Solutions

DNA repair mechanisms always have uncertainties because if an error were to occur at a proto-oncogene site then there will still be a risk for cancer. Passive and active shielding is a solution to reduce the amount of GCR and SPE exposure received by astronauts, thus lowering the frequency that DSBs are created in DNA. Due to the high penetrating properties of GCR/HZE ions, creating an environment that adequately protects humans is very difficult. Using these two shielding methods in unison along with the biological protection procedures would yield the best results, lowering the frequency of DSB repair errors and the consequent risk for disease.

Active shielding is a method that utilizes magnetic fields to deflect the charged particles, similar to the way earth's magnetic field and the resulting Van Allen belts, and similar to how a solar maximum causes a lower flux of GCR ions. Current theoretical methods for active magnetic shielding require a Ti-MgB2 superconductor wire to create a strong enough field to deflect ions. A B-field could be generated with a 100 m radius wire loop, with a current of 7.14x104 A $\pm$ 2.24 x 104 A as shown in Figure 10. The B-field formed with the toroidal superconducting wire would be able to shield from HZE ions by slowing them down to 5% of its original energy, for example, a Fe+26 ion from an energy of 2800 GeV down to 140 GeV. To prevent the magnetic field in the crew habitat, A smaller wire loop would generate

-1.08x104 A to negate the B-field within the habitat space. The B-field wire loops would weigh 7687kg. [65]

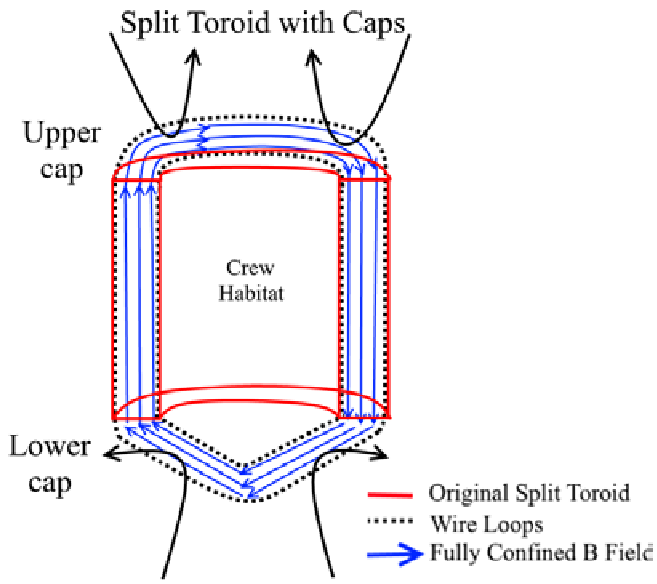

Figure 10: A diagram of what a potential toroidal magnetic field setup for the deflection of charged particles [65].

The other method of shielding is passive shielding which relies on physical mass to block the ionizing radiation. The most effective type of shielding comes from hydrogen based materials because of their high mass to charge ratio, allowing them to efficiently fragment heavy ions, stop protons (SPEs), and absorb neutrons. Materials like water and polyethylene (CH2) are materials that are high in hydrogen, however, it is not practical to build with them. One material that shows potential is Boron Nitride Nanotubes (BNNTs) polymers due to their resilience and low atomic number. The BNNTs also have the potential to be processed to incorporate high hydrogen polymers, however, they are still under research regarding properties and production [60].

5.11 Solutions for Radiation Damage on Medication

The other problem that needs to be addressed before a long duration lunar mission is the preservation of medication supplies. Medication supplies are important at preserving a space crew's health. With current technology, persistent radiation exposure over long missions will can degrade radiosensitive medication and can impair their potency and effect. There have been limitations in researching the radiosensitivity of drugs and the effects of high-LET radiation have on it due to the difficulty of replicating a space environment. The NSLR GCR simulation can not produce a full spectrum of GCR ions or even the spallations, which is responsible for 15% to 20% of the radiation exposure, limiting the replicability as a space radiation simulation. There has not been much research on this topic, since data is difficult to gather due to the lack of cargo brought back from space, limiting data. [20]

The only ways to counteract persistent radiation in the space environment is to produce more stable medicine that won't decay as fast to radiation and to protect the medicine with the previously mentioned passive and active shielding solutions. Materials with high hydrogen content such as polyethylene packaging will be more protective than its counterparts. Active shielding will create environments with lower radiation exposure, which will also contribute to medicine stability.

6 Helium-3 Locations and Abundance

Solar wind irradiates the lunar surface which deposits ^{3}He, and the amount of ^{3}He in the regolith then is determined by the amount of solar wind and the ability of the regolith to capture it. Its ability to capture the ^{3}He is largely determined by the titanium content (Ilmenite, $FeTiO_3$), which can be measured through multispectral imaging of the lunar surface. Here it was found that research predicts [54][49] there to be upwards of 15ppb of ^{3}He within the lunar regolith. 80% of the ^{3}He is expected to be found in regolith particles in sizes $< 50\mu$, which makes up 50% of all ^{3}He containing-regolith. Combining this data of ^{3}He concentration, and multispectral imaging data of the lunar surface, it was calculated that there may be upwards of 2.5 million tons of helium-3 on the lunar surface [49], the vast majority of which is located around the equator on the near side of the moon.

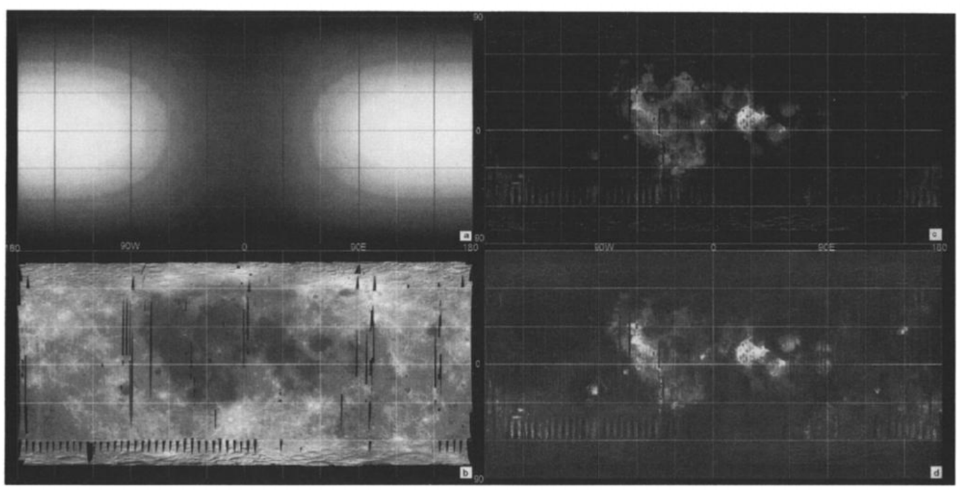

Figure 11: Each image shows a cylindrical projection of the moon with the left side of each image corresponding to 180 degrees west longitude. The grid shows 30 degree increments. (a) Solar wind fluence, (b) surface image, (c) Ti02 Abundance map, (d) helium-3 abundance map. Image credit: [54]

Table 2: This table shows the reported abundance of ^{3}He in different landing sites as well as the type of region each site was in. Data credit: [49]

Station	^{3}He abundance, ppb	Estimated Regolith Thickness, m	Region, Category
Apollo - 11	15.1	4.7; 4.6; 4.4	Mare region, Category I
Apollo - 12	7.1	3.7; 4.6; 5.3	Mare region, Category II
Apollo - 14	5.7	8.1; 8.5	Mare region, Category III
Apollo - 15	4.4	6.0; 4.4	Highland region, Category IV
Apollo - 16	1.4	10.1; 12.2	Mare region, Category II
Apollo - 17	8.0	7.0; 7-12; 8.5; 6-8	Mare region, Category II
Luna - 16	7.9	4.0; 4.0; 1.0-5.0	Mare region, Category II
Luna - 20	3.1	9.2; 0.4; 11.6	Highland region, Category IV
Luna - 24	3.4	2.0; 2.0-3.0; 3.9	Mare area, Category IV

Table 3: This table calculates the total amount of ^{3}He within each category and the total calculated amount within the lunar surface. Data credit: [49]

Category	TiO_2 wt%	Area $STiO2$ km^2	^{3}He Abundance, ppb	Regolith Thickness, m	Density kg/m^3	^{3}He Probable Reserves, tons	^{3}He, %
I	5-10	487114	15.1	4.4	1900	61491	2%
II	3-5	1518587	8	4.8	1900	110796	4%
III	1-3	1586312	5.7	8.1	2000	146480	6%
IV	0-1	34340315	3.1	10.1	2000	2150391	87%
Sum						2469158	100%

Using the energy released from ^{3}He - ^{3}He fusion and the estimated amount of helium-3 on the lunar surface, the total energy available from harvesting this resource can be determined. First the mass, m, of the helium-3 is calculated and then converted into moles, n.

$$m = 2.5 \times 10^6 [tons] = 2.2679625 \times 10^{12} [g]$$
$$M = 3.016u \tag{1}$$
$$n = \frac{m}{M} = 7.52 \times 10^{11} [moles]$$

The energy per reaction, E, is defined and then multiplied to the number of moles and Avagadro's number to obtain the total energy, E_{tot}, released by reacting every helium-3 atom.

$$E = 12.86MeV$$
$$E_{tot} = \frac{1}{2} N_A n E = 5.82 \times 10^{36} [MeV] \tag{2}$$
$$E_{tot} = 9.33 \times 10^{11} [TJ]$$

This number is then compared to the global energy consumption (580 million Terajoules) to find the number of years this amount of energy would last.

$$\frac{9.33 \times 10^{11} [TJ]}{5.8 \times 10^8 [TJ/yr]} = 1,609 [yrs] \tag{3}$$

The assumptions in this calculation are that the fusion reaction process is 100% efficient and can be entirely transferred and used on Earth. It is also assumed that the energy consumption is constant, which is not the case; the current annual energy consumption is increasing by $\approx 3\%$ each year. Accounting for the 3% energy consumption increase, the total lifetime of this resource is reduced to 296 years. This number can be increased due to the solar wind implanting more ^{3}He over time, although no specific number of atoms per unit time could be found which would aid in this calculation.

Another means of extending the lifetime of ^{3}He as an energy source would be to extract this material from other sources. Since solar wind irradiates every planet in the solar system, we can expect to find some amount on each planet. The irradiation decreases with the square of the distance to each planet, so the inner terrestrial planets would be more preferred. Atmospheres also block the ^{3}He from being implanted in the surface material, so a planet with no atmosphere is also preferred.

The planet Mercury has an extremely thin and non-protective atmosphere, and has an orbit less than half that of the Earth. The flux of solar wind therefore is roughly four times greater than the moon, so we can expect to find a large amount of ^{3}He on this planet. Although this is good to consider, there are several reasons we aren't proposing this planet as a resource. For one, the temperatures range from 430° C to -180° C. Secondly, besides the temperature being a large obstacle for robotic operations it also decreases the ^{3}He retention in the surface material, making Mercury a less viable option.

Thus, for this report we will continue to examine operations on the lunar surface since it is the most ideal source of ^{3}He.

7 Moon Outpost

7.1 Trajectory

The free return trajectory[70] is a technique that utilizes the influence of gravity by various celestial objects to achieve minimum fuel consumption and optimize travel route. Like the name suggests, the free return trajectory is a route that was discovered by NASA that provides a solution with minimum to no maneuvers once the spacecraft enters the key circle of influence. The process of the free return trajectory is done by the following:

1. Launch from Earth and briefly enters Earth's orbit
2. Provide sufficient power to leave Earth's orbit and be briefly influenced by the Sun's orbit
3. The astronaut will maneuver the spacecraft to enter the Moon's orbit
4. The spacecraft fully enters the Moon's orbit and surrounds the Moon's orbit from behind
5. At the exit point of the Moon's orbit, the spacecraft now has sufficient escape velocity to leave Moon's influence
6. The spacecraft enters a free route that flies toward the Earth
7. Re-enter Earth's orbit and eventually land on Earth

The steps above are demonstrated by the following diagram:

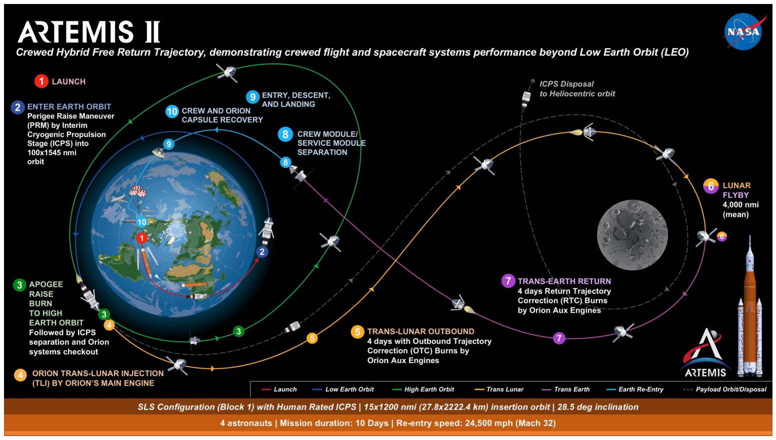

Figure 12: Trajectory proposed by the Artemis program [9].

To measure the path, we took consideration of the Moon, the Earth, and the Sun. To describe this path, we set the objects in a restricted three body perturbation problem[31] by considering object m_1 and m_2 are moving under a common gravity. Now place these objects on a non-inertial, co-moving frame of reference x, y, and z like the following diagram.

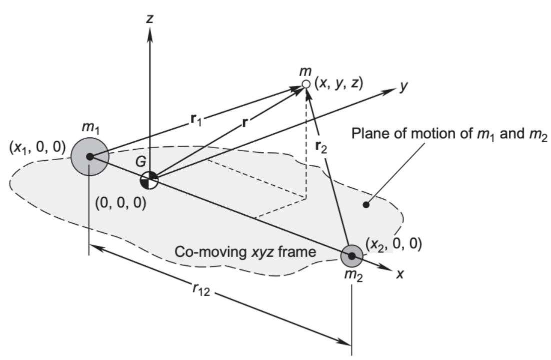

Figure 13: Restricted three body problem [31]

Mathematically, Fig.(13) can be represented in the following:

$$\ddot{x} - 2\Omega\dot{y} - \Omega^2 x = -\frac{\mu_1}{r_1^3}(x + \pi_2 r_{12}) - \frac{\mu_2}{r_2^3}(x + \pi_1 r_{12}) \tag{4}$$

$$\ddot{y} + 2\Omega\dot{x} - \Omega^2 y = -\frac{\mu_1}{r_1^3} y - \frac{\mu_2}{r_2^3} y \tag{5}$$

$$\ddot{z} = -\frac{\mu_1}{r_1^3} z - \frac{\mu_2}{r_2^3} z \tag{6}$$

For our frame of reference, m is the moon, m_1 is the Sun, and m_2 is the Earth. Then the r_1 is the distance from m_1 to m, r_2 is the distance from m_2 to m, r_{12} is the distance between m_1 to m_2. μ_1 is Sun's gravitational constant and μ_2 is the Earth's gravitational constant. X, y, and z is a coordinate system relative to the center of mass G, which allows $\dot{x}$ as velocity in x axis, $\ddot{x}$ as acceleration in x axis, and similarly for y and z. Ω is the inertial angular velocity. Lastly, the πs are defined in the following:

$$\pi_1 = \frac{m_1}{m_1 + m_2} \tag{7}$$

$$\pi_2 = \frac{m_2}{m_1 + m_2} \tag{8}$$

where μ is each respective gravitational constant.

[31] evaluated the influence of the Sun and Jupiter's gravitational force. The following figure shows spacecraft's trajectory before and after the influence.

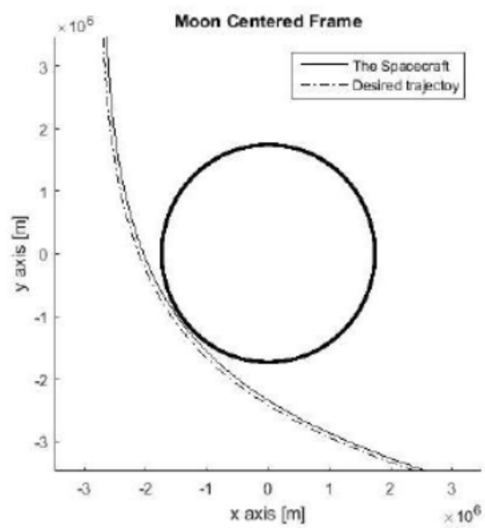

Figure 14: Free return trajectory with Sun's interference [70].

Data has shown that Jupiter's presence is negligible, however, if one look closely in Fig.(14), Sun's influence drifted the spacecraft closer to the Moon. When Sun's influence is taken into consideration, the spacecraft will obtain a perimoon altitude of 56.28km, which presents a risk of crash. It is necessary during the planning process to allow higher perimoon altitude.

The free return trajectory has other benefits as well. If the spacecraft entered the orbits correctly, the space craft will be able to approach a periselenum radius within a few hundred kilometers of the Moon's radius. This can be beneficial for observation and landing of our equipment. This route also lowers our overall transit time to 138 to 140 hours which means frequent missions. Most importantly, this can be automated for robots to enter different orbits with high accuracy and limits human error.

7.2 Outpost Locations

The location of a preliminary lunar base will be largely determined by several key factors. These include sunlight for solar panels, proximity to shadowy areas for temperature control, mild surface conditions, and water ice. Sunlight will be used as an initial power source, while the shadowy regions will provide a temperature difference, and potentially contain water ice [10]. The water ice can be extracted for use as water or for hydrogen and oxygen through an electrolysis reaction. Other byproducts of mining - and helium-3 mining in particular - can also contribute to fuel production and life support. Several locations around the south pole have been chosen since they are around useful craters. The crater edges allow for access to shadowed regions while being close to predetermined locations of predicted water ice. The south pole will allow for communication and a line of sight with Earth [9].

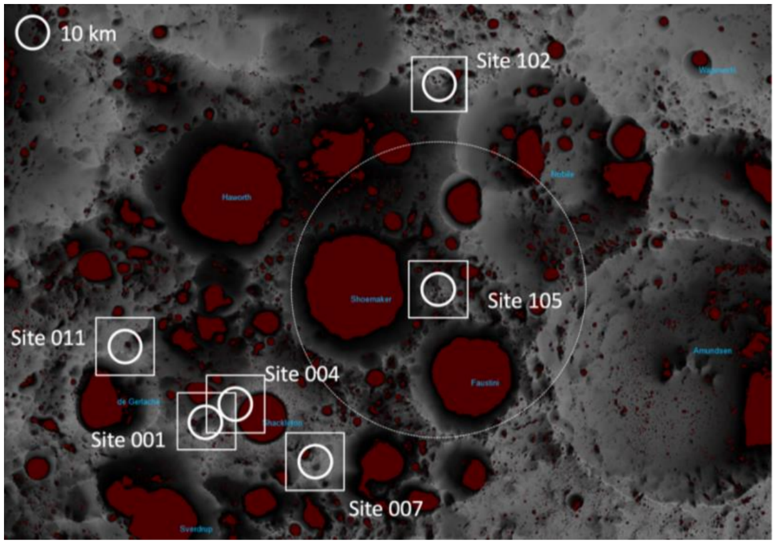

Figure 15: Six potential sites for a lunar outpost (locations marked with 10km-wide circles), Red areas depict locations and shapes of nearby craters. Image source: [9]

7.3 Fusion Reactor and Energy Transmission

The Artemis program has planned to send fission nuclear reactors on the moon that will support their series of missions. By 2030, NASA[58] intended to send 10 kilowatts of lightweight fission surface power that are expected to continuously run for 10 years. These fission reactors are pre-installed on the Earth and the dimensions of these reactors are 12 feet long by 18 feet wide. Each nuclear reactor will not weigh over 6000kg, staying under the typical 6500kg limit.

The fission reactor will focus on using low enriched uranium fuels, which are relatively safe for the spaceship to carry on board. This exact system was also demonstrated to migrate onto Mars, hence, the system will be able to withhold even the most difficult environment on the Moon. This paves the way for a functional moon base and provides energy for the construction of a fusion reactor.

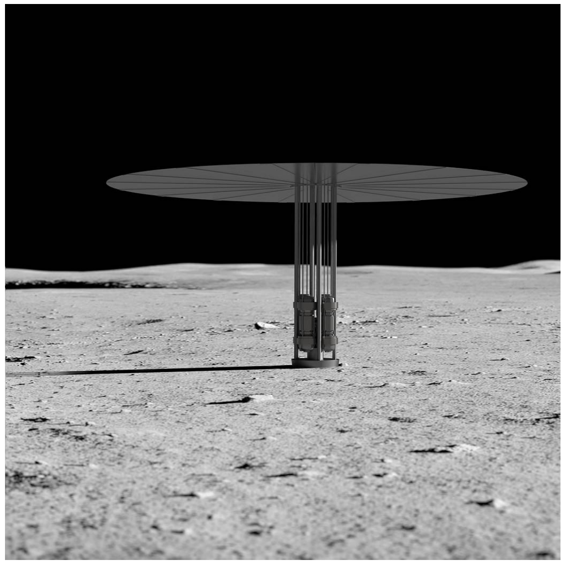

Figure 16: A visualization of the Fission Reactor on the Moon [60].

The next step of the plan is discovering the potential of building a fusion reactor on the Moon. The current blueprint is to build the fusion reactor on the Moon by sending several modules to simplify the install process. Two of the biggest limitations for a fusion reactor are size and the capability of containing the plasma it creates. The most promising fusion reactor in the making is an ongoing project by MIT[24] and the Commonwealth Fusion system.

MIT and Commonwealth Fusion System's new design looked to improve their magnets to enforce a large electromagnetic field to contain the plasma. Their new high-temperature superconducting magnet can produce 20 Tesla, requiring only 30 watts instead of the typical 200 million watts to operate. The dimensions of these magnets are 10 feet tall and 5 feet wide which made them possible to be carried into space. They utilized a newly discovered material, rare-earth barium copper oxide(ReBCO), which holds a stronger magnetic field and high superconducting critical temperature.

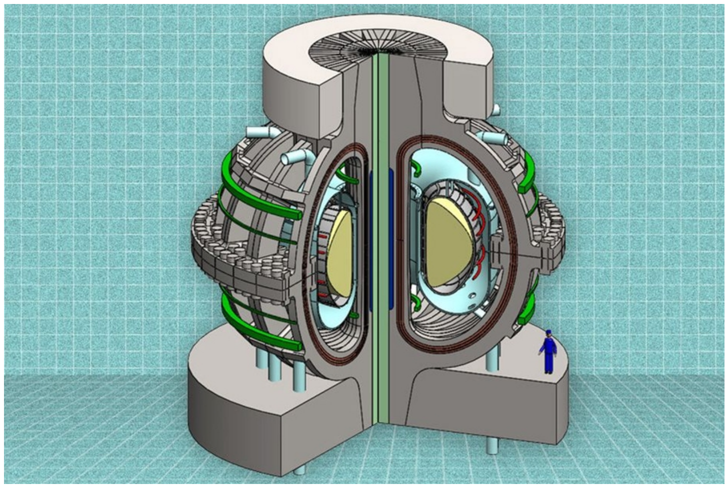

Figure 17: Fusion Reactor made by a team from MIT and Commonwealth Fusion System [40].

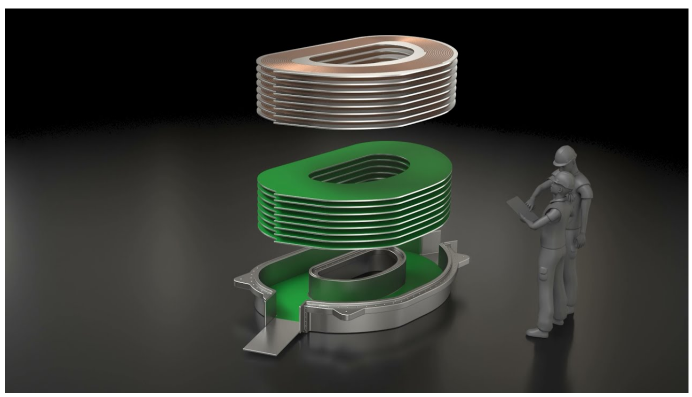

Figure 18: Magnet designed by MIT and Commonwealth Fusion System [24].

Once we have successfully constructed a fusion reactor on the Moon, we have to explore gathering the main source of For a ^{3}He-based mission, the south pole is not ideal. The majority of predicted ^{3}He deposits are located along the equator on the near side of the moon. This means that a future large scale operation will need to comfortably access a large and hazardous region. In order to do this, we will need to develop methods of coping with the extreme temperatures.

7.4 Dust Mitigation

Using collected reports [53] from the Apollo missions regarding the effects of lunar dust, several key effects were determined. False instrument readings and loss of traction were determined to be solved issues due to the advancement of computer-guided landing systems, AI, and material science. [12][48][57] The two other problems found were the clogging of mechanisms and surface buildup. For connectors or any moving part, micrometer-sized particles of lunar dust present threats of abrasion and clogging even in very well sealed joints or mated surfaces. Through LSIC (Lunar Surface Innovation Consortium) resources, one developing technology was found called a "permeable membrane electrical connector", being tested by Honeybee Robotics. [38] This device completely covers the mating surfaces with a permeable membrane until enough pressure is applied and the connecting pins puncture the membrane to connect with the receiving end. This ensures the connecting surfaces are never in contact with the environment. Tests showed it could go through 50 mate/demate cycles without any electrical resistance from the dust simulant, although they report that "1000's of cycles is attainable".

The LSIC also made us aware of the electrodynamic screen. Its purpose is to shield surfaces such as solar panels from collecting lunar dust by emitting an electromagnetic field above the surface. This is done by embedding sets of parallel conducting electrodes made of transparent indium tin oxide within a transparent sheet of plastic which is then fixed on top of the surface. The electrodes can be adjusted with either a single-phase or three-phase excitation to generate standing or traveling wave voltages across the screen in order to transport dust particles. It was found [39] that the three-phase drive-induced traveling wave was more efficient because it added a translational velocity to the dust particles, and with an energy consumption of 10 Watts per square meter, dust removal efficiencies of 85-90% were

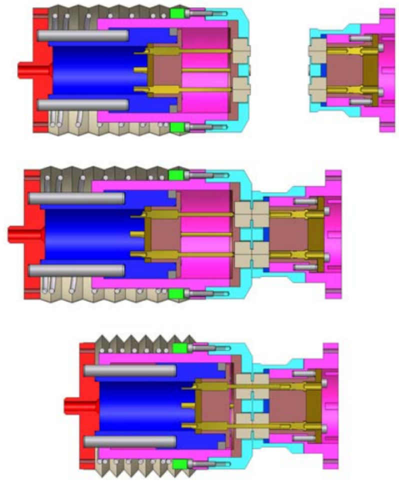

Figure 19: A three-frame sequence showing the mating process of the two connector ends. The pins (colored gold) remain behind the membrane (colored tan) until the two membrane surfaces contact each other (second frame). Then the applied pressure pushes the pins through the membrane to make the connection (third frame). Image source: [38]

achieved.

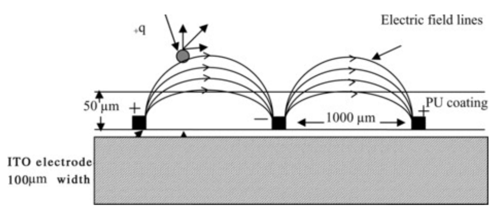

Figure 20: A single-phase excitation is shown producing an electric field between the electrodes which carries a particle away from the surface. Image source: [39]

7.5 Robots

Previously, there have been several iterations of a lunar mining robot concept developed by the University of Wisconsin [15] simply titled Mark I, II, III, and eventually the Mark IV. In the resource cited, Mark III is shown with a bucket scoop-type mining device and maneuvers using four sets of tracks. It is reported to have a 3m excavation depth, 1258 tonnes/hr excavation rate, and 556 tonnes/hr processing rate extracting 66 kg of ^{3}He per year. Using the Mark III concept and the detailed statistics provided, a separate feasibility study from 2014 [14] determined that roughly 1,700-2,000 of these rovers would be required to supply the Earth with 10% of the global energy demand.

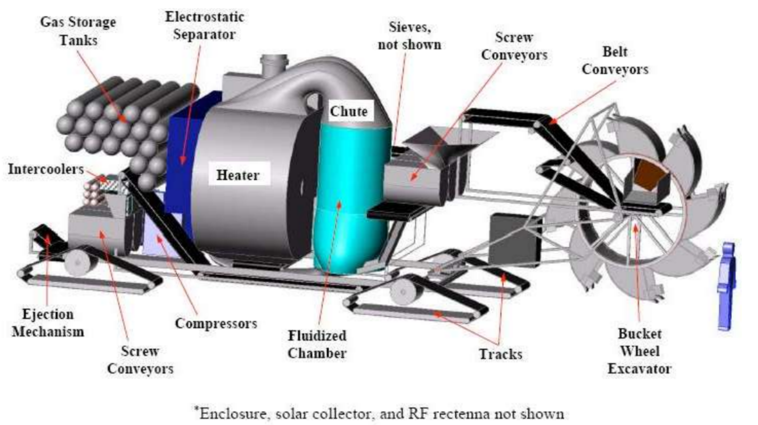

Figure 21: Visual of the Mark III Lunar miner concept designed by the University of Wisconsin. Image source: [15]

To use robots such as these to excavate, extract, and transport the ^{3}He is just one method of using robots. Another approach to consider uses several different types of robots each with its own role. This is what the company, Offworld, [7] is doing. These robots are designed around a core platform which is then expanded on to fit the role each of them is assigned. These robots use AI to learn about their surroundings and to communicate with others. In the concept designed by this team, they will be small, about 60x20 cm in length and width, and weigh 53 kg. They are designed to be easily launched from Earth and be extremely versatile. Each role is based on a modular attachment that will be added to the core platform of each robot. This way there is minimal redesign and manufacturing needed between each role.

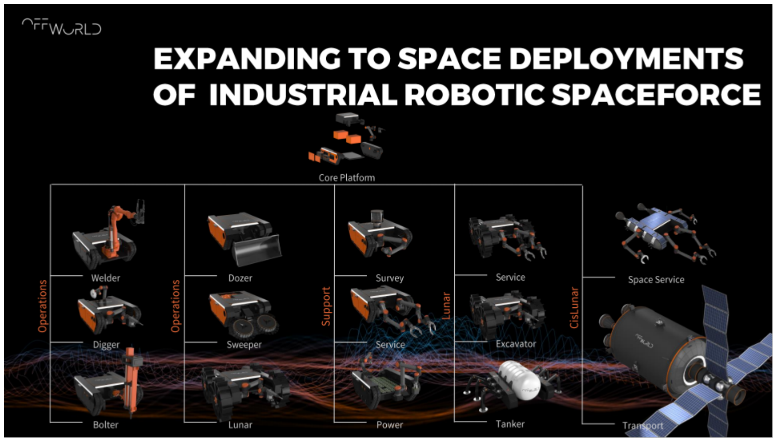

Figure 22: A diagram showing the different roles each robot would be responsible for, and their shared common platform. Image source: [7]

These robots cannot be continually sent from Earth, however. The next advancement needed is making these robots replicable on the lunar surface, taking advantage of the resources available. Such a process is achievable, as demonstrated by two companies, Relativity Space [6] and Redwire [11]. Relativity Space has developed 3D printing on a large scale, allowing the production of reusable rockets within 60 days, with 100x fewer parts, and using designs previously impractical via traditional methods. Applying such innovation in design and automated manufacturing will be invaluable for the lunar mining operation as it will reduce the need to send robots to the lunar surface.

The next breakthrough in technology is the use of lunar regolith as printing material. This has been done on Earth, but further testing must be done in low-gravity environments to ensure its efficacy. This is what Redwire has done with their AMF (Additive Manufacturing Facility), a zero-gravity 3D printer which has been operational on the ISS since 2016 [6]. It is able to 3D print small parts in a zero-gravity environment, and they are actively working on making modifications to the printer head and beds to accommodate lunar regolith material. When such processes for manufacturing or 3D printing the robots on the moon is established, the only resupply theoretically necessary would be the computer chips used to operate the robots.

8 Solar Panels

8.1 Energy Absorbance on Earth

In our three steps method on transferring energy from the Moon to the Earth, this section focus on the final step of the process: Evaluate potential solutions for receiving energy on Earth.

In the realm of solar panels, the efficiency of a solar panel is determined by the band gap width within the panel. A band gap width is the voltage difference between the p-n junction which decides how much energy it takes to excite an electron to move from one section of the solar cell to the other. For a single p-n junction solar cell, it was limited by the Shockley-Queisser(SQ) limit that to 33%. The SQ limit presents a standardized condition for the testing of solar cells. While 33% was converted into electricity, a majority of the remaining energy either converted to heat or simply passes through the solar cell. Below is a diagram that was illustrated by Shockely and Queisser [56] to address the relationship between band gap and efficiency.

The Shockely-Queisser(SQ) limit shows two downfalls in the single p-n junction: On the left side of this graph, when the band gap is less than 1eV, this means that the incoming energy provides more than sufficient energy required for the electron to transit between the junction. Therefore, a lot of energy will turn into excess energy which leads to lower efficiency. On the other hand, when the band gap is above 1.4eV, a significant drop in efficiency is due to the minimum energy required to transit electrons between the junction, therefore, a lot of photons will simply pass through the gap without providing any excitement on the electron. To bypass the SQ limit, we looked into quantum dot solar panels and multi-junction solar cells.

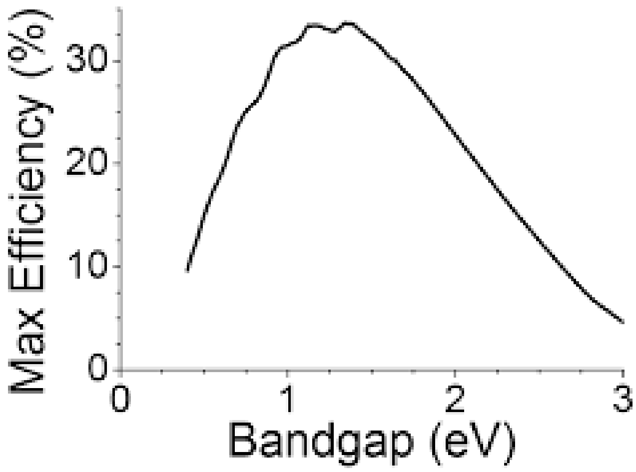

Figure 23: Shockley-Queisser limit [56].

8.2 Quantum Dot Solar Panel

Quantum dots [41] presents a property advantage over traditional solar cells. Quantum dot solar panel is capable of adapting their size to accommodate material's exciton Bohr radius, where the quantum confinement effect will become discrete energy level. As a result, it will form an energy gap with various energy levels that allows a wider spectrum of energy. The energy levels in a quantum dot solar cell is described by:

$$E_n = \frac{\pi^2 \hbar^2}{2mL^2} n^2, n = 1, 2, 3... \tag{9}$$

where $\hbar$ is Planck's constant divided by 2π, n is the level it is on, m is the mass of the electron, and L is the length of the confinement.

Moving forward, the band gap can be written as:

$$E^{QD} = E_g^{bulk} + \frac{\hbar^2\pi^2}{2R^2}(\frac{1}{m_e} + \frac{1}{m_h}) - \frac{1.8e^2}{4\pi_0 R} \tag{10}$$

where E_g^{bulk} is the band gap of the material, R is the radius of the quantum dot, m_e and m_h is the effective mass of an electron and the effective mass of the hole respectively.

Eq.(10) is a combination of three terms: the first term is a given value, the second term represents the particle in box that is dependent on the value of radius and the third term is simply the coulomb attraction between the electron and the hole. With that in mind, we can pick the ideal material in the following diagram using Eq.(10):

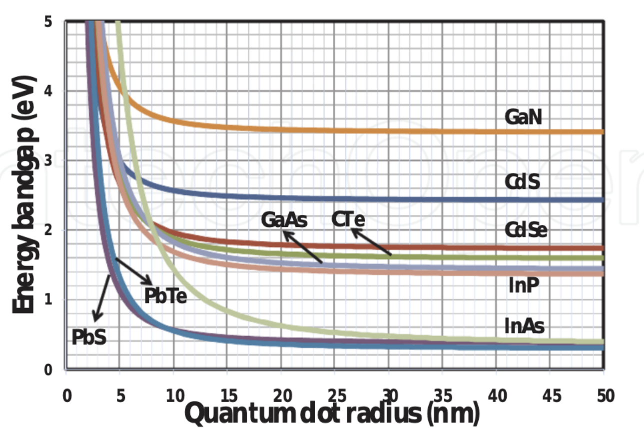

Figure 24: Band Gap Energy versus quantum dot radius from various semiconductors [28].

From the property of quantum dot solar cells, we aim for the largest energy band gap in the smaller quantum dot radius in Fig.(24). Therefore, PbS is the semiconductor that we are looking for.

Quantum dot solar panels also solve the issue of lost photons. When the band gap grew beyond the incoming wave, Auger annihilation is another property in quantum dot cells that salvages light in the "second" layer. This salvaging system contains two components: a sensitizer and an emitter. The sensitizer collects the excess light and transfers excitons to the emitter and the emitter will then fuse the excitons and send a higher energy singlet exciton to the "primary" level of the solar cell. The entire process can be denoted by the Jablonski diagram in the following:

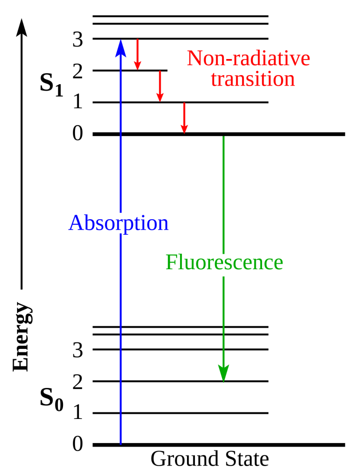

Figure 25: Jablonski diagram illustrating the absorbance and emission of a triplet-triplet annihilation [25].

Quantum dot solar cell has shown to significantly boost the efficiency with the property mentioned above. In contrary to the limitation that single p-n junction presented, in theory, the quantum dot solar panel can produce an upward of 66% efficiency. However, as of January 2021, the highest efficiency was 15.1% (stabilized power output of 14.61%) done on a $CsPbI_3$ perovskite quantum dot solar cell.

8.3 Multi-Junction Solar Cell

Multi-Junction solar cell[29] is very much like the triplet-triplet annihilation method presented in the Quantum dot solar cells. Multi-junction devices act as filter-like machines that have decreasing band gap down the layers. The efficiency of a multi-junction solar cell, like a single p-n junction solar cell, can be calculated by the following equation:

$$\eta = \frac{FFV_{OC}I_{SC}}{P_{light}} \tag{11}$$

where FF is the fill factor, V_{OC} is open-circuit voltage, I_{SC} is the average current produced by the solar cell, and P_light is the input power. V_{OC} and FF are given below:

$$FF = \frac{V_M I_M}{V_{OC}I_{SC}} \tag{12}$$

$$V_{OC} = \frac{kT}{q} ln(\frac{I_L}{I_0} + 1) \tag{13}$$

V_M and I_M are highest voltage and maximum current respectively.

Since P_light, V_M and I_M will remain constant, having more layers that collects more energy which will increase I_{SC} and therefore, increase the overall efficiency of the solar cell.

While the potential conversion efficiency of a multi-junction solar cell can increase to 65%, one with infinite number of junction can provide up to 85% efficiency. However, there is several trade-offs in the making of these solar cells. Resistive loss, optical loss due to refractive index differences, and most importantly radiative recombination.

With that in mind, we find the state of the art for a multi-junction solar panel. A six-junctioned solar panel, which demonstrated an upward of 47.1% efficiency with AM1.5D sun spectrum and 39.2% efficiency under AM1.5G sun spectrum. The construction of the solar cell is shown in the diagram below.

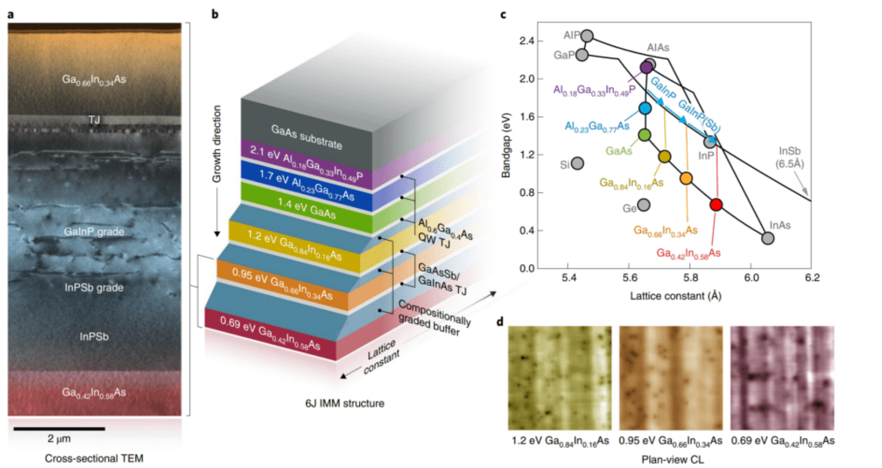

Figure 26: Six-junction Solar cell [29].

The theory of making an ideal multi-junction solar cell is very straightforward. Unfortunately in practice, there are other obstructions in making the perfect multi-junction solar cell such as the fabrication between layers. Multiple layers and inconsistency among the materials made it easy to create an unmatched intersection that doesn't allow a smooth transition between layers for the photons. For that reason, many photons were either trapped in the previous layers or it is not sufficient to pass down to the next junction.

9 Laser Transmission Paths

The paths that a laser could take between the Earth and the Moon are dependent on the locations of the satellites transmitting them. Once determining the locations of the satellites, the distances that laser would have to travel can be calculated. The first arrangement proposed uses three lasers coming from the equator of the moon and traveling to three different Lagrange points L1, L4, and L5. The lasers would then be reflected to three different equidistant satellites in geostationary orbit where the lasers would then be transmitted to the Earth's surface.

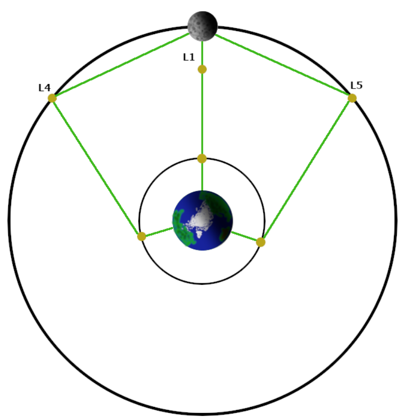

Figure 27: Three possible laser paths (in green) are plotted between satellites (yellow dots) placed in Lagrange points labeled L1, L4, and L5. The inner black ring represents the geostationary orbit, and the outer black ring represents the moon's orbit around the Earth.

Such a setup was chosen to minimize correction burns needed by the satellites to maintain orbit and accurate aim, as well as provide the laser with a minimal distance to travel through Earth's atmosphere. The maximum and minimum distances between each satellite were calculated as well as the angles the laser would subtend during transfer between the Lagrange points and the geostationary orbit.

Table 4: This table describes the distances of each leg between the satellites and shows the angle each Lagrange satellite must subtend.

Geostationary	Surface - Satellite	$\Delta\theta$	Satellite - Satellite	Satellite - Earth
L1 Short	57,835 km	6.816 °	284,401 km	35,786 km
L1 Long	57,835 km	6.816 °	307,658 km	35,786 km
L4 Short	382,662 km	5.146 °	342,236 km	35,786 km
L4 Long	382,662 km	5.146 °	407,123 km	35,786 km
L5 Short	382,662 km	5.146 °	342,236 km	35,786 km
L5 Long	382,662 km	5.146 °	407,123 km	35,786 km

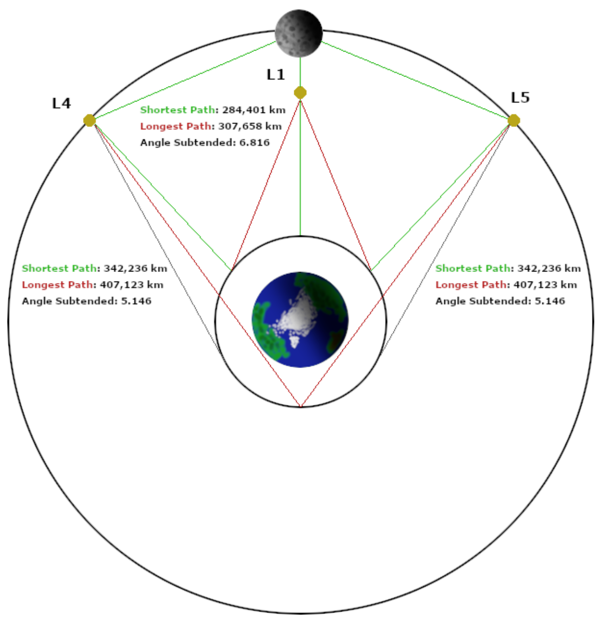

Figure 28: For each Lagrange point, the green lines represent the shortest distance the laser will travel from this point to geostationary orbit, and the red lines represent the longest distance the laser will have to travel. The gray lines indicate the maximum angle through which the laser will subtend.

10 LASERS

10.1 LASER theory

It is very well known that LASER is an acronym, but very few actually know what it stands for. LASER means light amplification by stimulated emission of radiation. The terms seem confusing, but what actually happens is the feedback loop of light going back and forth in cavity amplifying in the process. In electric circuits this kind of system is usually referred to as an oscillator, so the acronym should be LOSER instead, but clearly that sounds worse. As a consequence of that generating procedure, we get the main feature of laser: coherence. Coherence is the main property that makes LASERs useful for all kinds of purposes, but specifically applicable to the needs of our project, which is the energy transfer. Its origin is the Quantum Mechanics and specifically that the energy states for electrons are quantized and discrete. For electrons to jump from one energy level to the other, there must be either energy absorption or emission and both of them are done using photons. Since the difference between energy values is very specific and material dependent, when photon goes down it will exert a photon with that exact energy value. Mathematically that can be expressed as the following formula

$$\Delta E = E_2 - E_1 = h\nu \tag{14}$$

where $h = 6.63 * 10^{-34} Js$ is the Planks, constant and ν is the frequency of the light wave measures in Hz. We can also express energy in terms of the wavelength, which has become the standard for most papers. Frequency and wavelength of Electromagnetic wave (in vacuum) are related by the following:

$$\nu * \lambda = c \tag{15}$$

Where λ is the wavelength of the light wave measured in nanometers and c is the speed of light, $c = 2.99 * 10^6$ m/s as shown in Fig.(29)

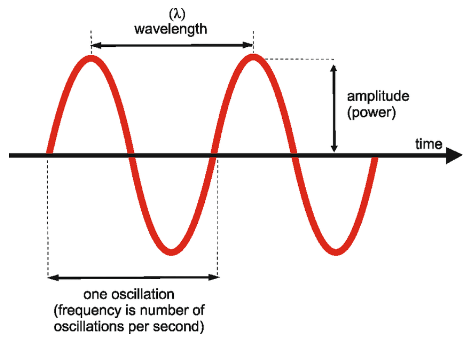

Figure 29: Relationship between wavelength, frequency and power illustrated [51].

The phase part is slightly tricky. There are 2 things that can occur: stimulated emission and spontaneous emission.Stimulated emission occurs when there is a near by photon, which triggers the quantum effect causing the electron to go down in energy level. When that occurs, there is an additional photon produced that has the same phase as the the one that triggered the reaction. Spontaneous emission has a lower probability of occurring, but can be very problematic because it will emit a photon in any direction with any phase, which can be very damaging to the laser.

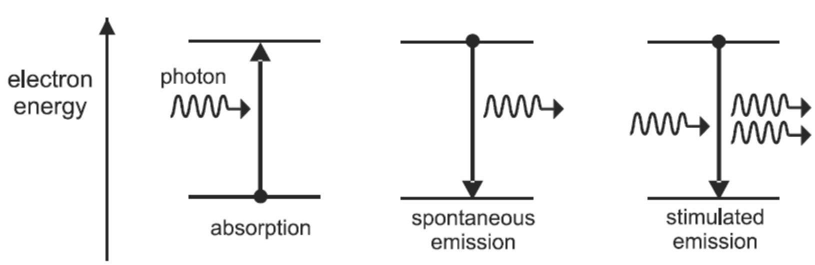

Figure 30: Drop between n=1 and n=2 energy levels with the release of a photon [51].

Spontaneous emission creates a big problem with lasers[44] because that signal can be amplified using other electrons creating a chain reaction, therefore, destroying coherence or even causing back-reflection, a case where the laser shoots back in the optical circuit destroying it in the process. This issue coupled with the fact that only very specific frequencies are allowed to be initially produced caused an inherent limitation to the technology. The reasons described above show themselves in applications in the industry: the most common type of laser YAG:ND laser tends to operate at 1084 nm, which is equivalent to the infrared range. The way to get higher frequencies usually follows the following stages:

1. Creation of the source using Master Oscillator usually in the infrared frequencies
2. Multi-stage amplification and isolation of the infrared frequencies
3. Change of the frequencies of the light using crystals

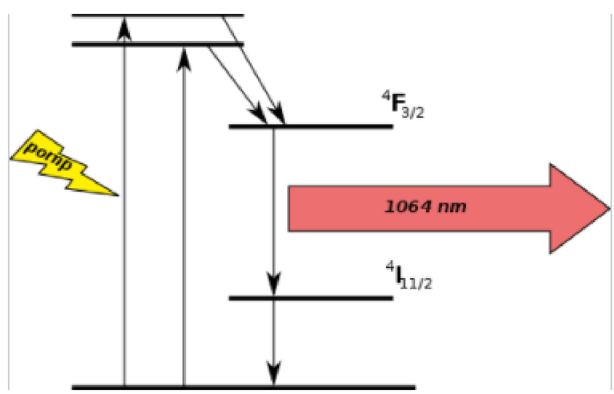

Figure 31: Structure of laser. First electrons are excited to F orbital, but when they transition down the exert a photon reflecting the energy difference between the orbitals [51].

All of this will become crucial when we start talking about the main purpose of laser light in this project: delivering energy from the moon. So first let us examine how lasers propagate through space. To do so we have to take advantage of some

Quantum Mechanics, specifically the theory of wave packets. The concept of a wave packet is not incredibly difficult to understand, it is just a study of multiple waves traveling together. The confusing part begins when one starts to consider the way the waves interact with each other, because then we have to start thinking of wave-like probability amplitudes that each photon creates. The tricky part is to have them cancel out in such a fashion so that the light continues to propagate as a single object with the smallest possible spatial spread or in the frequency domain. Such wave packets are denoted as Gaussian wave packets or packets of minimum uncertainty.

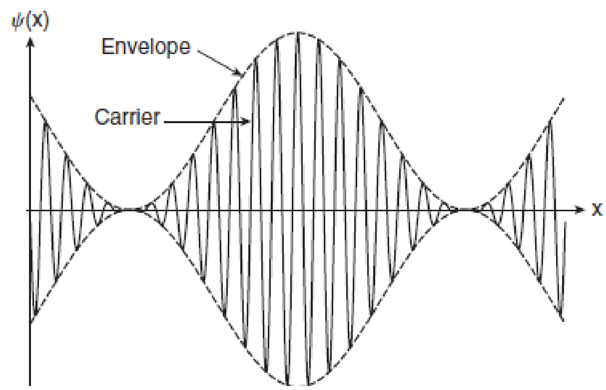

Figure 32: Gaussian wave-packet [47].

So now we want to investigate the spread of such packets over the space because we desire to transfer TW worth of power, so being accurate is crucial. It just so happens that the Gaussian wave packet is actually the quantum mechanical description of the perfectly coherent light. For all means and purposes, we use diffraction to minimize the spread so the equations that follow will resemble that.

For example the spread of the Gaussian beam with lowest possible spread is

$$\theta = \frac{\lambda}{\pi w_0} \tag{16}$$

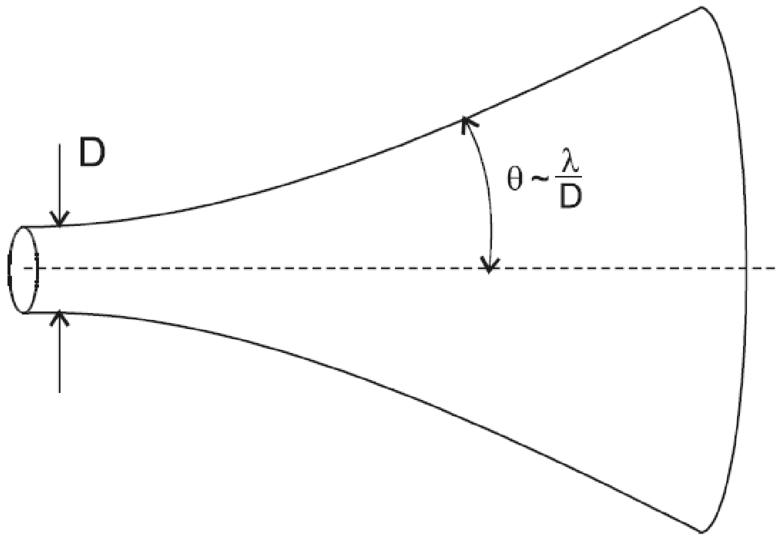

Figure 33: Spread of electromagnetic waves [51].

Where w_o is the initial radius of the beam. Thankfully we can make the wavelength very small therefore making the spread minimal, but to do so we will need to create pulses of the highest possible frequency. Unfortunately, there are very few records of such technologies online, and one of the main reasons for that is because of the interaction between light and media. This is what the next section is mostly focused on.

10.2 Polarization effects on laser technologies

In order to truly understand this topic, we need to quickly remind ourselves of the main principles of electromagnetism. All classical electrodynamics is fully expressed in the following Partial Differential Equations known as the Maxwell's equations:

$$\begin{aligned} \nabla \cdot D &= 0 \\ \nabla \times E &= -\frac{\partial B}{\partial t} \\ \nabla \cdot B &= 0 \\ \nabla \times H &= -\frac{\partial D}{\partial t} \end{aligned} \tag{17}$$

We are mostly focused on the study of the first term in Eq.(17). D is defined as the electric displacement and it is equal to the combination of the already present electric field coupled with the Polarization vector, which is the induced electric field created by the displacement of charges in matter with associated coefficients.

$$D = \epsilon_0 E + P \tag{18}$$

We assume that the media in which the laser is generated is uniform and is a func-

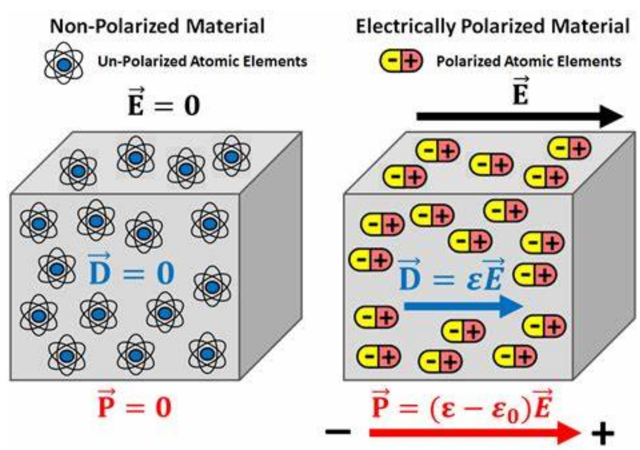

Figure 34: Visual effects of the polarization [37].

tion of Electric field of different powers. Physically that is related to the transition between different orbitals and therefore expressing different dipole moment. This allows us to express Polarization vector as the following:

$$P = \epsilon_0 \chi^1 (E) + \epsilon_0 \chi^2 (EE) + \epsilon_0 \chi^3 (EE) + \epsilon_0 \chi^4 (EEE) ... \tag{19}$$

Here ϵ_0 is the vacuum permittivity and χ^n is the n-th order component of the electric susceptibility of the medium. Due to the symmetry considerations. Essentially if the material is symmetric along the light propagation χ^{2n} is effectively 0, because the effects are independent on direction of E. This allows us to only focus on the third term and higher, so let us see how a the most common interaction between Polarization vector and Electric field will look like:

$$E = E_0 + E_\omega cos(\omega t) \tag{20}$$

Here [37]E is the superposition of some external electric field and an incoming wave. The wave could be part of our laser system whereas we could set up the external field to our benefit depending on our needs. For the materials with symmetry along the wave propagation vector all even polarization terms will cancel out, also the lower terms tend to dominate resulting in the following expression:

$$P = \epsilon_0 (\chi^1 + \frac{3}{4} \chi^3 |E_\omega|^2) E_\omega cos(\omega t) \tag{21}$$

Let us now introduce another term to separate the nonlinear effects and linear. Linear effects are present in every material while nonlinear effects only emerge for very intense electric fields or special materials with separation between energy levels.

$$\chi = \chi_{Linear} + \chi_{Nonlinear} = \chi^1 + \frac{3}{4} \chi^3 |E_\omega|^2 \tag{22}$$

From here we want to go back to classic optical coefficients of refractive index such that we can use already established ways of describing wave

$$
\begin{aligned}
n &= (1+\chi)^{1/2} = (1+\chi_{Linear}+\chi_{Nonlinear} \\
&= n_0(1+\frac{1}{2n_0^2}\chi_{Nonlinear})
\end{aligned}
\tag{23}
$$

where $n_0 = (1+_{Linear})^{1/2}$ is the linear refractive index. We can now use Taylor expansion we can have intensity dependent refractive indenx (IDRI) of

$$
n = n_0 + \frac{3\chi^3}{8n_0}|E_\omega|^2 = n_0 + n_2 I \tag{24}
$$

Naturally, the intensity of the beam is the highest at its center and decreases radially, so the refractive index will be doing the same thing. Unfortunately, that creates a sort of a lens that ends up focusing the laser even further increasing the energy density. In practice, the critical values are realisable with modern lasers which can

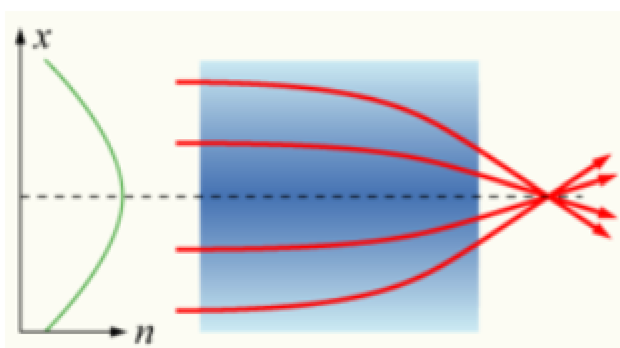

Figure 35: Formation of the pseudo-lens by intensity dependent index [56].

exceed PW powers. For example, a laser delivering 50 fs pulses with an energy of 1 J has a peak power of 20 TW. So we have to be careful when amplifying such lasers, because there is a theoretical limit that does not allow us to work with TW values.

10.3 Chirped Amplified Lasers

As discussed in the previous section the main issue with high powered lasers occurs when the intensity reaches a certain value. Once it does, self-focusing starts increasing the intensity by itself causing a major issue, so what if instead, we were able to pump the laser with power without ever reaching those critical values? This is exactly what Chirped Amplified Lasers do. Instead of the classic approach that consists of some Master Oscillator setting up the signal, then multistage amplification to output signal Chirped Amplified Lasers insert an additional stage where the signal is stretched out, therefore, limiting the energy density. In order to accomplish that, a pair of gradings is used that reflects electromagnetic waves with different wavelengths down different paths therefore stretching out the pulse both spectrally (frequency domain) and spatially (position domain). The pulse is then amplified using conventional methods of pump fiber and such, and then compressed back with the similar pair of gradings.

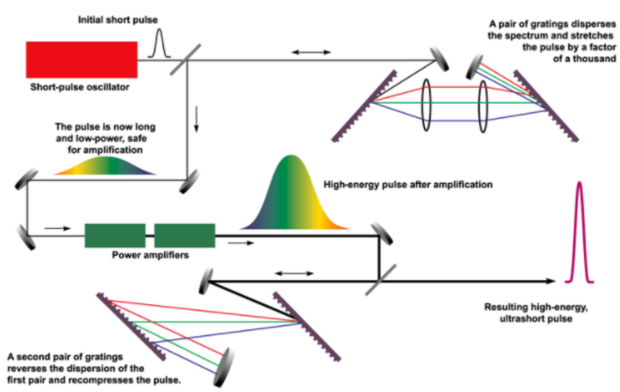

Figure 36: Optical circuit for the Chirped Amplified Lasers [27].

Chirped Amplified lasers are very efficient in compressing and amplifying signals[55]. There are works that go as low as 460 nm for the wavelength of the signal, which should be spread small enough to make it possible to send energy to Earth. The next major question that requires answering is the way that the light will interact with the atmosphere.

10.4 Scattering in the atmosphere

Sending the laser through space may seem difficult at first, however because there is no matter in outer space, the lack of absorbance and scattering makes this simpler. Unfortunately, the atmosphere has many different molecules of varying electric charges, creating a great barrier for most cases of radiation. The spectrum of the atmosphere can be seen below:

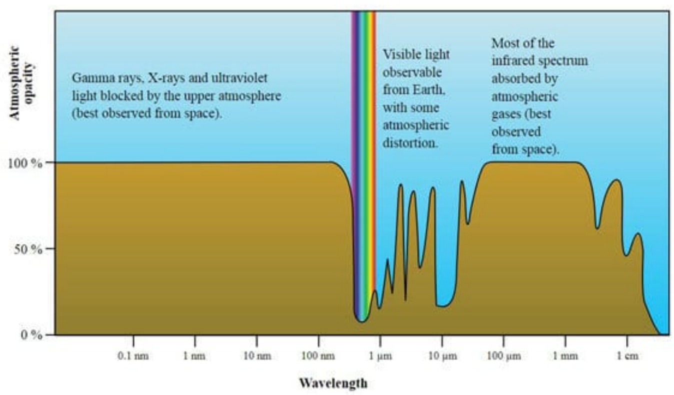

Figure 37: Spectrum of Electromagnetic radiation in the atmosphere [1].

The main theoretical explanation for that is the so-called Rayleigh scattering. It is another return of the previously mentioned Polarization vector, but this time we are polarizing very specific molecules of water, ozone, and oxygen. The oscillating electric field of a light wave acts on the charges within a particle, causing them to move at the same frequency. The particle, therefore, becomes a small radiating dipole whose radiation we see as scattered light. The particles may be individual atoms or molecules; it can occur when light travels through transparent solids and liquids but is most prominently seen in gases. Clearly, it is the most applicable to the smaller particles in the atmosphere: if a particle is big enough to be comparable to the wavelength it is studied by a separate branch of Mie scattering.

The math of the Rayleigh scattering gets very complicated rather quickly, so the most important result we get from it is the following

$$\sigma_s = \frac{2\pi^5}{3}\frac{d^6}{\lambda^4}(\frac{n^2-1}{n^2+2})^2 \tag{25}$$

Where σ_s is the Rayleigh scattering cross-section and it is proportional to $\frac{1}{\lambda^4}$

It means that the fraction of light scattered by scattering particles over the unit travel length (e.g., meter) is the number of particles per unit volume N times the cross-section. For example, the major constituent of the atmosphere, nitrogen, has a Rayleigh cross-section of $5.1 * 10^{-31}\ m^2$ at a wavelength of 532 nm (green light). This means that at atmospheric pressure, where there are about 2×1025 molecules per cubic meter, about a fraction 10^5 of the light will be scattered for every meter of travel.

Unfortunately, this is the supposed wavelength that has been required to send the pulse from the space station on the moon. This leads to the current predicament of the project: either finding a way to increase the wavelength near the atmosphere bounds or somehow isolate the beam from the atmosphere. There are some concepts such as creating a 4 km long tube that would accept the laser, but that would be highly unstable due to the wind.

There are other issues of the loss of coherence of light due to the turbulence that occurs very rapidly in the turbulent flow, so overall it would make a lot more sense to either figure out a way to convert the energy near the atmosphere or use it for the further exploration of the outer space or the needs of the moon base.

10.5 Microwave Wireless Power Transmission Technology

One of the JAXA[5] team has developed their system based on microwaves, at less than 10GHz, which is safer for human eyes and capable of penetrating cloud cover and rainfalls. The problem that has been presented to them is to develop a strategy that can accurately transfer microwave beams with a pointing accuracy of 0.001 degrees, which then we can transfer energy safely and efficiently from a distance of 36,000km. Their solution provided a two-step process, first, they will use the amplitude monopulse method to detect the arrival direction of a pilot signal.

The amplitude comparison monopulse method[23] is a measurement of the angular error presented across multiple antenna beams and therefore provides an estimate of the angle of the target. The transmitter will emit a signal in a sum pattern and the receiver receives a different pattern and sum pattern. The error signal can be expressed as follows:

$$e = \frac{\Delta}{\Sigma} cos(\theta) \tag{26}$$

Where the difference pattern is Δ and the sum pattern is Σ. Assuming there are four antennas to receive beams placed equally on a square receiver. The sum pattern can be expressed as following:

$$\Sigma = 4AG_0 \tag{27}$$

G_0 is the voltage gain of the antenna beam at the track axis, and A is the amplitude measured at these antennas. Afterward, the azimuth error and the angle error on the track center will be evaluated by:

$$\theta_{azi} = \frac{\theta_{3dB}\varepsilon_{azi}}{k_m\Sigma} \tag{28}$$

$$\theta_{ele} = \frac{\theta_{3dB}\varepsilon_{ele}}{k_m\Sigma} \tag{29}$$

θ_{3dB} is the 3dB beam width, ε_{azi} and ε_{ele} is the difference pattern picked up by the receiver, and k_m is the coefficient of monopulse error. Once the system is set up correctly, it will be able to map the tracking of the transmitter in respect to the track axis like the following diagram.

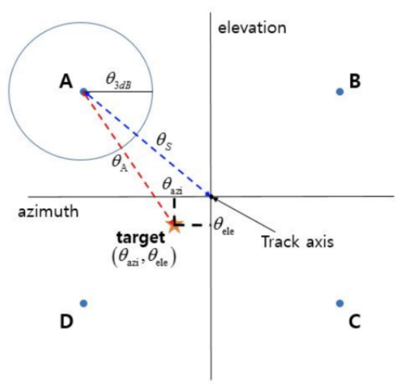

Figure 38: Mapping of the target in respect to the track axis with the azimuth error and angle error [23].

This method allowed the JAXA to set up an experiment with a pilot signal of 2.45GHz and successfully transmitted 5.8GHz of high power microwave. They designed a mission distance of 55 meters and showed an 18.3% efficiency. While the method still has room for improvement, this has promising results that provide alternative solutions compared to a laser based energy transmission system.

11 Discussion

With the project as complex as the one that is being proposed in this paper, there of course will be many issues with implementation. Here we outlined a series of topics for the future consideration and research.
There are many seemingly minute details in these biological proposals, however, when these details are not taken into consideration, they can lead to many other issues. For instance, gene therapy at the germ-line level can cause many unknown mutations to occur. Currently, no approved gene therapy has been conducted at the germ-level for humans. Not only would there be a possibility of off-target mutations, but there are other ethical concerns as well. For the application of synthetic chromosomes, as well as dormant chromosomes, further research would have to be made of the viability of storing extra chromosomes in the human cell. The cell would have to have the capacity to store these chromosomes, but a mechanism of deactivating and reactivating them would have to be determined. The specific radioprotective genes that would be inserted into the human genome either through gene therapy or synthetic chromosomes were also not determined in this IQP. A vector with the radioprotective genes embedded would have to be created in order for the genes to be successfully transported into a cell's genome in gene therapy. The addition of chromosomes, as seen in aneuploidy, leads to genetic instability as well.

As for finding new radioprotective pathways, HeLa cells, D. Radiodurans, and chernobyl studies may prove to be useful at finding cellular pathways that protect against low-LET radiation and non-direct DNA damage. The shortcomings of this method, however, is that they will likely not be useful towards high-LET GCRs and SEPs due to the increased intensity of radiation damage caused. There is more hope to be found in improving the current DSB repair pathways to reduce the amount of DNA deletion during repair. If it is possible to improve the rate of high fidelity HDR repair by reducing the rate of NHEJ or the more deleterious a-NHEJ, this would prove to be a viable solution to reducing the rate of cancer and radiation induced disease. This however also has a lot of hurdles to clear, mainly finding a method of therapy and understanding the ethical implications, as we do not know the side effects of proposed methods, and there would require thorough research and many trial phases. Though unrelated, this would not only benefit astronaut health on space expeditions, it would also benefit humanity as a way to protect workers in high radiation environments, as well as patients undergoing radiation therapies to reduce off target radiation damage to the body.

The locations of the ideal lunar outpost for humans and the location of helium-3 are in two vastly separated regions. For this plan to be implemented, further development must be made in the area of extreme environment technologies in order to relocate the outpost location towards the equator. Alternatively, a plan involving a larger range for helium-3 transportation could be devised, although it would be much more challenging. The computations for the lifetime of helium-3 as a resource could be expanded to account for more realistic variables. The replication of robots via lunar 3D printing must also be proven with either a regolith simulant or samples of actual regolith material.

The energy transmission phase is heavily dependent on the maintenance of the lasers on the moon. Currently there are very few available research projects of lasers operating at the power output that is required. At TW power range a lot of physics becomes radically different from the one that is being commonly taught, so the specific technologies proposed in the earlier sections will have to be heavily tested. Another major issue is the conversion of the frequencies at the entrance to the atmosphere from 300 nms to 1600 nm range, which is not a trivial issue. An excess of energy could become catastrophic if some part of the relay system fails, so before full implementation the team in charge should absolutely make sure that there is a back up plan. Another issue that has not been addressed is the thermodynamics of the system and the effect of heat on chirped laser modulation that historically has been an issue with lasers.

The solar cells are well experimented and provide promising results. However, the issue is how do we maintain them as their efficiency lowers over time due to space dust or potential damage by asteroids. In addition, there is no existing research on how much energy these solar cells can take, must of these experiments are done in ideal situation by 143suns. Taking consideration by the abundant energy we are transferring, we must also consider the situation here on the Earth. If given more time, we would we would have further discussion on the distribution for this immense energy.

12 Conclusion

After considering the results of our research, we are brought back to our original question: Can we use the fusion energy from helium 3 on the Moon to help with the energy crisis? To answer that question, we have established four areas of research as outlined in the introduction. Part of the team spent time researching space radiation because it is one of the most impacting problems that must be taken into consideration when astronauts journey into space. Space radiation is not only prevalent, but also dangerous. There are several different types of space radiation, but the most important and unavoidable ones include HZEs. Some possible solutions to counteract HZEs include passive/active shielding and altering the human genome to include radioprotective genes.

Many of the theoretical solutions to space radiation involved some sort of gene manipulation. Many of the proposed solutions have not yet been fully investigated, and many complications can arise when drastically adding elements to the human genome. Despite this, it was important to think outside of the box. Many years ago, there were many things that were not possible. Now, there has even been patients who have undergone gene therapy and was able to survive and live through their debilitating, genetic disease. If gene therapy was safely applicable in other applications, humanity would very much benefit. Not only would many genetic diseases be curable, but also genes with different adaptive attributes could be inserted into the human genome to help the person survive in harsher conditions.

The planning of our presence on the Moon and the methods of sustaining that outpost were built off of the Artemis program by NASA [9] . We were inspired by their plan and further explored the possibility of constructing a fusion reactor on the Moon. The fusion reactor by MIT and the Commonwealth Fusion System showed promising results on providing a compact and functioning solution. The technology required for the robotic systems needed at this outpost are well on their way towards being fully developed and tested, as shown by Offworld's modular and AI-driven robots. The 3D printing of such robots with lunar regolith material has yet to be proven effective, but the technology required to accomplish replication looks promising. Dust mitigation has provided a challenge but is on track to be a solved issue for mechanical systems and solar panels.

The study of the chirped amplified laser in theory allows to avoid many problems in transmission of the light from the lunar outpost. The chirped laser can amplify the beam as much as we want without causing damage to the gain medium, which as the result lifts the restriction on how much energy we can pump into the laser. This area seems very useful, because we are planning on generating basically infinite amounts of energy by means of nuclear fusion. The part where the light must travel through the atmosphere is less straightforward, because overall there are a lot more interacting parts. Thankfully that is the area of science that is well established, so our team could use many resources that are avail be. There are still some issues to be established that felt outside the scope of our team, but we believe that even those issues can be solved in the near future.

We have fully inspected a feasible system by JAXA[5] that allows laser transmission with high accuracy. This system will be implemented throughout all three stages of laser transmission from the Moon to the Earth. The relay system that we are using to relocate these energy will have an absorb and release process, we have covered the absorption with two of the most efficient solar cells in research and released with chirped amplified lasers.

Answering the earlier question, "is this project possible?" our team believes that the answer is yes. This is definitely one of the most challenging and daring projects to be proposed, but the technologies that are required for its implementation are already here or we believe will be here within next couple of decades.

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