Human Aspects of a Lunar Research Station

BLISS: Base Lunar Installation for Scientific Studies

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***Abstract*—This report outlines human factors and considerations for the construction of BLISS, a large research station on the Moon. The crew of 50 will be composed mainly of scientists and divided into three teams, with a focus on crew selection, healthcare, and psychological support. Countermeasures for the effects of microgravity on the immune system, bones, and muscles will be implemented. Various challenges and solutions for establishing a lunar base are discussed, including power usage, water and food production, waste management, radiation protection, habitat design, circadian rhythm, medical care, lunar dust management, entertainment, pregnancy, and death guidelines. The importance of crew well-being, team spirit, and environmental sustainability are emphasized including communication with wireless mesh network. BLISS will strive to have a closed-loop life support system with its own air revitalization, a water recovery system, waste management system, and food production. Sintered regolith is evaluated as shielding against ionizing radiation for the lunar base and is shown to allow for perpetual stay. The exposure of construction crews, undertaking 5h of EVA per day, is estimated to limit their stay to approximately 7-9 months with a maximum dose of 80-100 mSv.**

***Index Terms*—Lunar base, Research station, Human aspects, Healthcare, Life support, Ionizing radiation,**

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I. Introduction

In the year 2037, the Artemis program has been concluded, re-sending astronauts to the Moon, sixty two years after the Apollo 17. The purpose of this mission is to build a large research station on the Moon, mainly for scientific research. This station needs to be designed to house up to 50 people. This report will focus on the human aspects of the mission. This study is therefore essential for the proper conduct of the mission where different elements will be studied, spanning from the medical aspects to the life support system.

II. Crew selection

A. Overall organization

The mission should allow fifty people to conduct scientific experiments on the Moon. The crew will be divided into three teams (two made up of seventeen members and one of sixteen) in order to make the station's equipment profitable. Each team will rotate every eight hours. In addition to their scientific work, people have to perform some tasks to run the station.

People selected will be therefore mainly scientists. Each team must have the following composition in order to meet all the needs of the station and to have an optimized organization. Tasks that do not require specific skills can be carried out by any available people.

	Occupation	Description
1	Commander	overall coordination
1	Pilot	drive the modules
2	Communication manager	lab report, communication with Earth
1	Therapist	crew mental condition
1	Doctor/Surgeon	crew health
1-2	Mechanical engineer	rover maintenance
1	Energy engineer	solar panels maintenance
1	Computer scientist/network engineer	network and communication
2	Physicist	scientific purposes
1	Biologist	
1	Botanist	
2	Geologist	
1	Chemist	

Table I: Crew distribution

B. Mental and physical condition

The people selected for this mission must be in good physical and mental condition.
Extensive medical examinations carried out before the mission will allow the detection of weaknesses which can cause the appearance of complications during the long exposure in space.
In the selection phase, astronaut candidates will also be confronted with different emergency situations on Earth, in order to observe their resistance to stress and their capacity to keep their self-control under pressure; these aspects constitute a pivotal factor in selecting the final crew.
On board, each member will be required to attend one individual therapy session per week, an hour long. The therapist is required to do that too, connecting to their own therapist on Earth via audio and video. The habit of journaling is strongly advised as well, since it was demonstrated to decrease mental distress and improving overall mental health [1].

III. Healthcare

A. Short term

In case of any injury the person will come in for a checkup using the basic medical kit or an ultrasound. If a person gets sick they can be put in a cautionary quarantine. In the case of a radiation leak or a delayed return from an EVA, countermeasures such as Potassium Iodide, Prussian Blue or DTPA will be ready. In extreme cases, fluids, blood transfusion or stem cell transplants will also be available [2].

B. Immune system

The immune system is negatively affected by microgravity and the generally more sterile environment on space stations. Despite the gravitational acceleration on the lunar surface is nonzero, it is still only $\frac{1}{6}$ of that on the Earth's surface.
This constitutes a problem, especially for T regulator cells: their function is to lower immune responses when infection is no longer threatening. Unfortunately, they show an abnormal behaviour in microgravity, getting activated and suppressing immune response before due time. Lymphocytes are also affected, showing a reduction in their activity [3].
To keep the immune system stimulated, vaccines will be provided to be administered periodically.
Diet and supplements can also be used to keep a healthy immune response: vitamins (C, D and K), antioxidants (spirulina and fruits) and Omega-3 fatty acids (seeds and nuts) will help to strengthen the immune system, while aiding other bodily functions as well [4], [5].

C. Physical Well-being

It isn't just the immune system that feels a lowered gravitation. Bones will lose density and muscles will atrophy if they aren't used enough. One countermeasure is training. On the ISS the astronauts train about two hours everyday, but that is also a μG environment while on the Moon there is as mentioned previously $\frac{1}{6}$ of the Earth's gravity. This leads to more natural usage of the body which allows for a reduction of training. On BLISS all personnel will workout at least one hour everyday or two hours every other day. Another comfort is an allowance of a 40L shower everyday or 80L every other day (up to each person to decide but may be lined up with planned workouts).
Available training methods will be a circular cycling centrifuge, mRED, cross trainers, flywheel exercise devices and resistance bands.

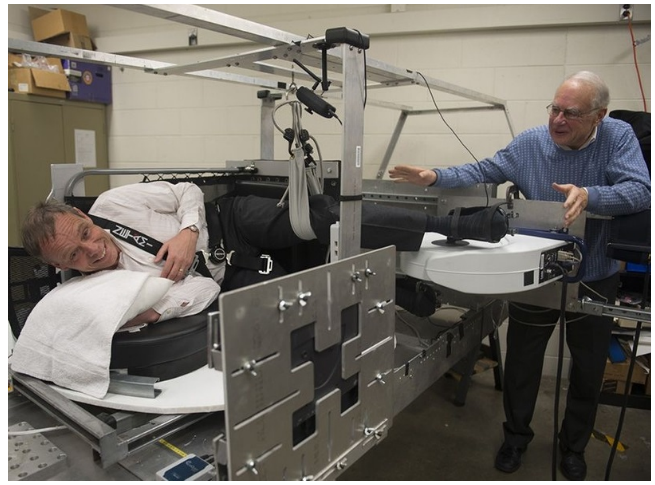

Figure 1: Fuglesang tests MIT centrifuge [6].

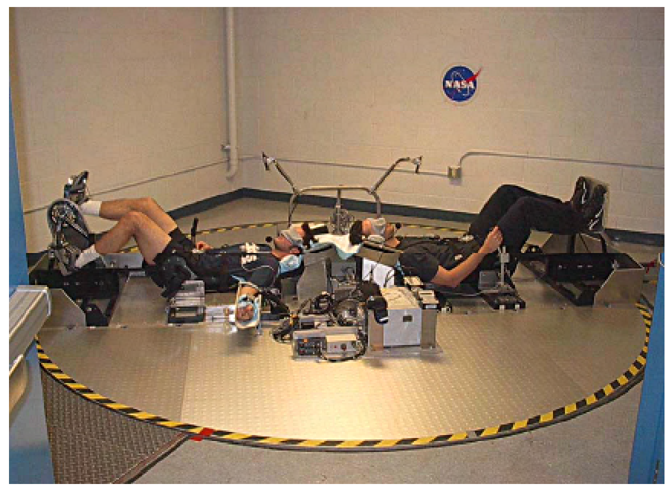

Figure 2: NASA Ames Human Powered Centrifuge [7].

Circular cycling centrifuge: Inspired by the classical merry-go-round and some more modern applications see fig. 1 & 2. This circular plate will house up to 8 people hungry for gravity. The cyclists lay their heads close to the centre and their legs towards to outside, they pedal to propel the machine faster and faster and can experience up to 4G on their lower body depending on tempo and electrical assists [7]. It can stimulate blood circulation and metabolism in the lower body, which are often impaired by microgravity or low gravity. This could help maintain muscle strength and bone density in the legs and prevent edema and varicose veins [8]. All this while also providing the fun and social aspects of a spinning class or group exercise.

Moon Resistive Exercise Device: This is an adaptation from the Advanced Resistive Exercise Device currently on the ISS. The MRED will not have a vibration dampener which saves weight (and isn't needed in the more structurally rigid lunar base). The MRED is a robust exercise machine used for primary exercises to stimulate bone regeneration and major muscle groups. It can also perform 15 secondary exercises for other muscle groups. It offers traditional upper and lower body exercises like squats, dead lifts, calf raises and bicep curls with a constant force throughout the range of motion. Using vacuum cylinders, it provides workloads up to 270 kg, with feedback to the astronaut and data to BLISS exercise physiologists. It aims to allow for heavy workouts even in low G [9].

Cross trainer: These are a good space alternative to the treadmill since the resistance isn't mainly from gravity. You can adjust the resistance to your liking by adjusting a braking system that provides more or less tension on the flywheel, making it harder or easier to pedal and providing both an upper and lower body workout.

Flywheel exercise device: It uses a spinning mass as resistance through winding up and releasing an actuation belt. The compact and lightweight FWED is designed for resistance exercise training against neuro-muscular de-conditioning and allows for back, trunk, and upper and lower limb exercises, including squat, dead lift, and heel raise [9].

Resistance bands: This is by far the least high tech tool for working out but it's still useful. They can be used for many different exercises and stretches. They don't weigh much or take up much space, all while not depending on gravity for tension.

D. *Circadian rhythm*

Each organism has an internal clock which is influenced by factors such as sunlight and temperature. During sunlight, serotonin is produced which causes us to feel energized. However, during night, melatonin is produced which causes us to feel sleepy. Thus, a 24-hour days structure with day and night phases is essential for the well-being of the inhabitants.

At each position on the Moon, the lunar day lasts approximately 29 Earth days with 14.5 days of daylight and 14.5 days of night. At the south pole, where the station is located, crater edges are exposed to near constant solar illumination, while the interior of the craters are permanently shaded from sunlight. It is thus important to system allowing to recreate the terrestrial day.

In 2017, the airline Emirates has developed virtual windows for passengers sitting in the middle row of the first class to have a live view out the side of the plane [10]. It is therefore possible to draw inspiration from this technology, by placing exterior cameras that broadcast the outside view in each room. The brightness of these screens can decrease at sunset to turn off during the night, then turn on again the next morning. This device would allow the rhythm of life on the station as the sun does on Earth. One main advantage of this device compared to a classic window is that it avoids the cosmic radiation from the outside. Other uses of these screens can be considered, as an entertainment system or to broadcast the view of the hometown of the person.

Figure 3: Emirates aircraft cabin [10]

E. *First aid care and Surgery*

A basic medical kit should be provided for each crew member with first aid content like wound and injury care, bandages and dressings, personal protective equipment, drugs and relief.

Due to the long duration of the mission, a small operating room with the basic equipment is needed. This room will allow to realise check-ups, to close wounds or to get a cast. Thanks to real-time communications, the use of robotic surgical robots controlled by real surgeons on Earth is possible [11]. This technology would access the doctor during an operation outside his field of competence.

F. *Moon dust*

Because of the absence of atmosphere on the Moon, there is no erosion due to wind or rain. This means that particles keep rough and angular shapes. The size of the lunar particles makes them very easily inhaled by humans, and particularly toxic for the body. When the lunar particles are electrically charged by the solar radiation, they cling to everything.

Microscopic particles (0.1 to 100 μg) can be trapped into airways and lung alveoli. Under these conditions, the lungs can no longer evacuate dust through the mucous membranes or coughing. Even smallest particles can end up in the olfactory bulb right into the brain. In the long term, inhalation of these dusts can cause bronchitis, damage DNA, cause cell mutation increasing the risk of cancer [12]. It is therefore important to regulate the quantity of particles in the station, use filters and ventilation systems to avoid exposing the crew to lunar dust.

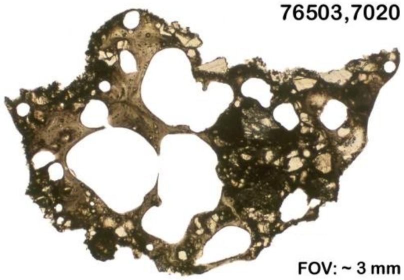

Figure 4: Lunar dust [13]

G. Entertainment on board

During free time, activities need to be provided to keep people busy on the station. The first and easiest solution is a multimedia catalog with a large choice of programs, such as movies, podcasts, books, TV shows. The virtual windows or a personal tablet can be used to broadcast this content. The crew can also make calls to their families on Earth. They are able to each bring a shoe box from Earth with their personal belongings, pictures of their family, good-luck charms or symbolic objects for personal comfort.

Other activities must be proposed in order to build a strong team spirit within the crew. Common areas should be designed to encourage people to spend time and eat together. Film screening and board games can be offered in the common areas.

H. Pregnancy

Pregnancy during the mission should not take place for multiple reasons.
Firstly, the station is strictly designed for fifty people and the presence of extra individuals would be a hindrance to the mission.
Furthermore, both pregnant women and young children have very specific needs that have to be satisfied through differentiated diet and healthcare; this is not feasible on the lunar base for both logistic and cost reasons.
The second main point is that studies [14] have proven how gravity loading is paramount for the correct development of the fetus during the second half of gestation. Low gravity would cause a delay in the formation of the muscular and cardiovascular systems. This, in turn, would lead to complications later in the developmental process of the child, for milestones such as sitting, standing and walking.
Therefore, pregnancy on the Moon cannot be carried out. Following NASA's official policy [15], sexual relations and conception will be strictly forbidden on the lunar base and female astronauts will be tested regularly in the 10 days prior to launch.

I. Death guidelines

People chosen for this mission have been scrupulously selected to be in good health and are subject to regular health check-ups. Unfortunately, an accident could lead to the death of a crew member during the mission and procedures are therefore necessary. The burial of bodies can cause environmental contamination and the use of bodies as fertilizer seems not conceivable for both biological and ethical reasons. One solution [16] is to place the body in an airtight body bag in the airlock. Here the temperature is low enough for the body to freeze. The bag could then be shaken by a robotic arm and the body reduced to small pieces through vibrations. After evaporating water from the remains through a vent, the bag, now containing powder, would finally occupy a very small volume; it could then be stored waiting to be brought back to Earth with the first available cargo spacecraft.

IV. Life Support Systems

For human survival to be possible at an isolated and inhospitable habitat like the Moon many things needed to be taken into account. Because of its isolation and the Moon's lack of resources the station can be looked at as a closed loop system. This means that all of the resources brought from Earth must be recycled, reused or repurposed as close to 100% as possible for the mission to succeed. The main categories for human survival were based on The Environmental Control and Life Support System, ECLSS, currently in use on ISS. The ECLSS include systems for air revitalization, water regeneration, temperature regulation and waste treatment. Food production was also added since the station needs to be self-sufficient for the long term success of the mission.

A. Air Revitalization

Atmosphere in the lunar base is supposed to be similar to Earth's atmosphere at sea-level, made up of nearly 79% nitrogen and 21% oxygen in volume. This reduces the likelihood and severity of fires compared to atmospheres richer in oxygen.
Pressure is kept constant at 1 atmosphere and temperature around 295 Kelvin, with a possibility to be slightly adjusted within a range of a few degrees.
This choice seems the most natural for both humans and plants living on the station, requiring the least adjustment, which could be key in terms of reducing bodily stress for such a long mission. Lower values for pressure, like $\frac{2}{3}$ atmosphere,

were also taken into account for the final decision, but then discarded since their detrimental effect on health has been demonstrated [17].
Moreover, the final choice suits the life support system selected for this mission, which is similar to the one on the ISS, where the values of the aforementioned parameters (air composition, temperature, pressure) are the same as described in this section.

Strictly regarding air revitalization, it is estimated that an individual needs on average 0.85 kg of oxygen per day, or 325 kg per year [18]. With a crew composed of 50 people, this translates into 16250 kg per year.
A big part of it can be generated via water electrolysis, splitting liquid water molecules into gaseous oxygen and gaseous hydrogen. This mechanism is at the base of the Oxygen Generation System [19], in use on the base. The oxygen is then supplied to the cabin, while the hydrogen enters the Sabatier System, as explained further in subsection B.

The crew will exhale more than 17.85 tons of carbon dioxide per year [18] that need to be either recycled or discarded. A CO_2 removal unit can be implemented, making use of amine-based anion exchange resin beds: these directly capture carbon from ambient air to alleviate excessive emissions, through chemical reactions [20]. Once desorbed, part of the CO_2 can be vented overboard, while the rest can be transferred to the Sabatier System to be recycled for water production.

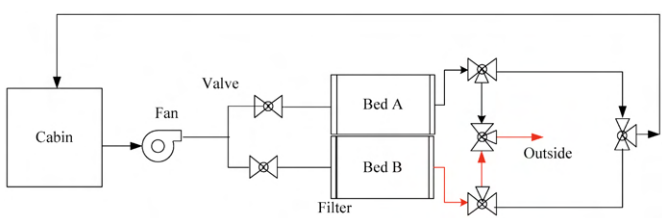

Figure 5: CO_2 Removal Unit Operating Scheme [21].

Leakage of cabin atmosphere due to airlock depressurization and other operations also needs to be taken into account.
In order to estimate it grossly, the same leak rate per unit volume as the ISS is assumed. In 2011, the pressurized volume of the ISS amounted to 899 m^3 and the leaks to 0.227 kg/day [22].
Considering that the lunar station is designed to have a volume of 6000 m^3, the leaks then result in a total of 1.5150 kg/day, or 552.9811 $kg/year$.
Assuming an air density of approximately 1.225 kg/m^3, roughly 451.4131 m^3 of atmosphere volume is lost per year, about 7.5% of the total. This means that at least $0.79 \cdot 451.4131$ m^3 = 356.6164 m^3 volume of nitrogen (at standard conditions) and $0.21 \cdot 451.4131$ m^3 = 94.7968 m^3 volume of oxygen need to be resupplied every year (436.8551 kg and 116.1260 kg respectively). While oxygen can be obtained via electrolysis from the water excavated on the Moon, cryogenic nitrogen can be shipped directly from Earth. These rough estimates need to be reviewed and corrected periodically, depending on the number of EVAs and operations scheduled.

B. Water Production and recycling

Water is an important part of the life support system and being able to produce and recycle water efficiently is crucial for the success of the mission. To be able to produce water, the station base will have a Sabatier System which currently also is used on the ISS [23]. The Sabatier System uses a catalyst that reacts with carbon dioxide and hydrogen to produce water and methane. Carbon dioxide is a naturally occurring byproduct from the human metabolic process and both carbon dioxide and hydrogen are byproducts from the Oxygen Generation System. This way there is a circulation of the available materials and as little waste of provided resources as possible [24].

The used water on the station will be divided into three categories like on the ISS. Gray water which includes condensation, respiration, hygiene and water recovered from the Air Revitalization System, ARS, and is the easiest to filter clean again. The second category is yellow water which is urine and it is the second easiest to filter clean. Last category is black water which is faecal matter which is the most difficult to extract any water from and will be treated under its own chapter IV-C Waste Management [23].

To recycle the used water the base will have the Water Recovery System, WRS which also is used on ISS. The Water Recovery System consists of two modules called the Water Processor Assembly, WPA, and the Urine Processor Assembly, UPA [25]. To increase the water recycling even more the Brine Processor Assembly, BPA, will be added on to the WRS and the final assembled system is shown in Fig. 6 [26]. The WRS is designed to recycle both gray and yellow water. The WPA has a series of different technologies to clean the gray water including filtration, ion exchange, adsorption, catalytic oxidation, and iodination [27] and is able to recycle 100% of the gray water [26]. The UPA distills the yellow water using Vapor Compression Distillation, VCD, technology [28] and recovers 87% of the yellow water. The distillate is then combined with the gray water and feed through the WRS which in total adds up to a 93.5% water recovery. The UPA produces a brine in the distillation of the yellow water which is why the BPA was added and that brings up the total water recycling to 98% [26]. Bringing the water recycling level up to 98% or more has been on NASA's Water Recovery Technology Roadmap as an essential capability for future human deep space missions [29].

C. Waste Management

To deal with the waste recycling, the Universal Waste Management System, UWMS, is implemented. The lunar base is designed to include 22 bathrooms, each one complete with

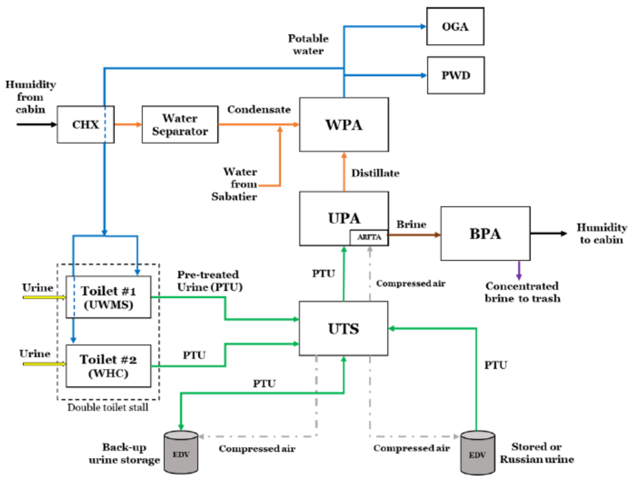

Figure 6: The Water Recovery System assembly with the WPA, UPA and BPA modules [26].

a toilet. These toilets are designed just like the one launched by NASA to the ISS in 2020 [30].
Normal toilets with "vacuum flush" technology, generally used on passenger aircraft, were also considered as a candidate for installation, but rejected for hygiene reasons and for not being complex enough. The gravity on the lunar surface is too low to allow them to perform optimally; toilets designed for micro-gravity perform much better in this environment, where the gravitational acceleration is five times closer to zero than to 9.81 m/s^2.

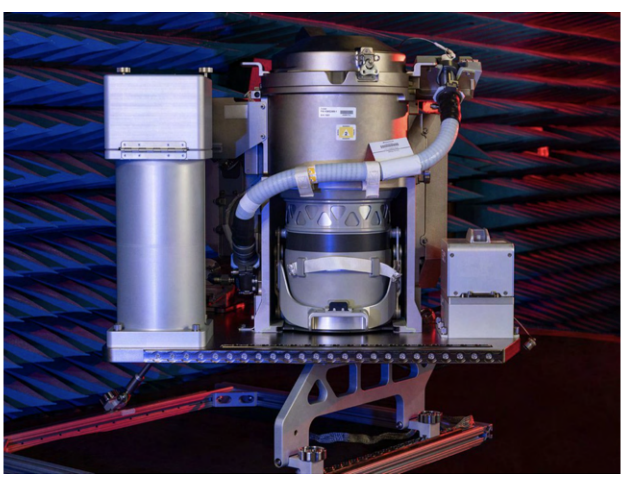

Figure 7: NASA's Universal Waste Management System [31].

The basic principle behind UWMS is suction: it uses air flow to pull excreta away from the astronauts' bodies into the assigned tanks. The advantage of this technology is that it has been developed and improved over a long period of time, hence its high efficiency and reliability.

On the ISS however, the faecal matter does not get recycled, but gets stored in bags until it can be shipped to Earth and burn up through the atmosphere.
The cargo ships do not seem like a feasible solution for the lunar base, for different factors: the presence of a higher number of people causing a higher feces production rate, the distance from Earth and the duration of the mission, all leading to unreasonable costs.
The obvious solution would be recycling faecal matter: a good candidate for it could be based on the HomeBiogas® digester [32], whose methanogen bacteria break down organic waste, creating methane and liquid fertilizer. The former could, together with the methane produced from the Sabatier System be used as added rocket fuel, while the latter could be used in the greenhouse as further explained in subsection D: "Food Production".
The existing technology, although fully developed on Earth, could find some limitations on the lunar base. Studies [33] have demonstrated how microgravity has an impact on bacterial cells metabolism; it should then be kept in mind that, although in this case gravity is not zero, it is low compared to the one on Earth, and microbes will likely undergo metabolic changes. Before being installed on the moon, this technology will then require some kind of optimization.

D. *Food Production*

For the mission to be a success long term the crew must be somewhat self-sufficient in growing their own food and not be completely reliant on space food. There will be a greenhouse on the station of 180 m^2 where the crew can grow their own food. The greenhouse will be divided into three parts, about 20% or 36 m^2 will be dedicated for fruits and vegetables. The remaining 80% will be divided in two equal halves for growing potatoes in aeroponics and soil respectively. Which results in about 72 m^2 for each farming method.

In the first part vegetables and fruit, leafy greens such as lettuce, spinach and kale as well as tomatoes, cucumber and strawberries will be grown by vertical hydroponics towers. Hydroponics is a soil-less farming system that submerges the plant's roots in water filled with the needed nutrients for the plant to grow. It uses less water per crop compared to regular farming in soil, it is more space efficient and it generally produces more abundant crops quicker than the traditional way. This is because the crops do not need to spend energy on growing roots down the soil in search of food [34]. There are both vertical towers, shown in Fig. 8, and horizontal shelves for hydroponics but because the vertical towers provide a better airflow and ventilation they were chosen for the mission [35]. The choice of which vegetables and fruit to grow was made because these crops tend to grow the best in hydroponics [36].

The second and third part of the greenhouse will grow potatoes in aeroponics and soil. Aeroponics has many of the same advantages as hydroponics such as requiring up to 98% less water than soil based farming and being space efficient. The main difference, as seen in Fig. 9, between the two is that for aeroponics the roots of the crops hang freely and will be sprayed with nutrient enriched water with regular intervals instead of constantly submerged in the water. Potatoes grow

Figure 8: Leafy greens growing on vertical towers for a better air circulation [37].

in the root systems of the plant and therefore tend to grow better in aeroponics than hydroponics [38].

Growing potatoes in soil usually takes 3-4 months from planting to harvesting and only gives one harvest. If grown in aeroponics the potatoes will be ready to harvest in about 1-2 months and can then continue to be harvested for up to 6 months. Using the Kennebec potatoes and planting with a density of 24 potato plants per m^2 it is estimated to get about 10 kg of potatoes per m^2 after about a months time. Using a harvest cycle of once every seven days the potatoes will continue to produce about 10 kg of produce for the remainder of its vegetative cycle [39].

In the third part of the greenhouse potatoes will be planted traditionally in soil. This will act as a backup in case something were to happen with the hydroponics and aeroponics crops as well as be the base for any bio-related research or experiments. When planting in soil it is important to give each potato plant enough space for the potatoes to grow. Giving each plant enough area to grow on will result in about 4 plants per m^2 and each plant will produce about 2 kg of potatoes on average which gives a total of 8 kg potatoes per m^2 [40].

Potatoes were chosen as the main starch to grow because they are nutrient dense and also need less area and water to grow compared to rice or other grains. After being harvested potatoes are ready to be cooked whereas other starches, such as different types of grain, need further processing before cooking. Potatoes can also be cooked in many different ways to give variety to the crews diet [23]. Another way to introduce variety in the diet is through the fresh fruits and vegetables that will be grown on the station. This way the crew will not have to rely on space food for fruits or vegetables and will also have the familiarity of the foods from home on the station.

Counting about $4 \cdot 72 = 288$ regular potato plants, $24 \cdot 72 = 1728$ aeroponics potato plants and $80 \cdot 36 = 2880$ vegetable

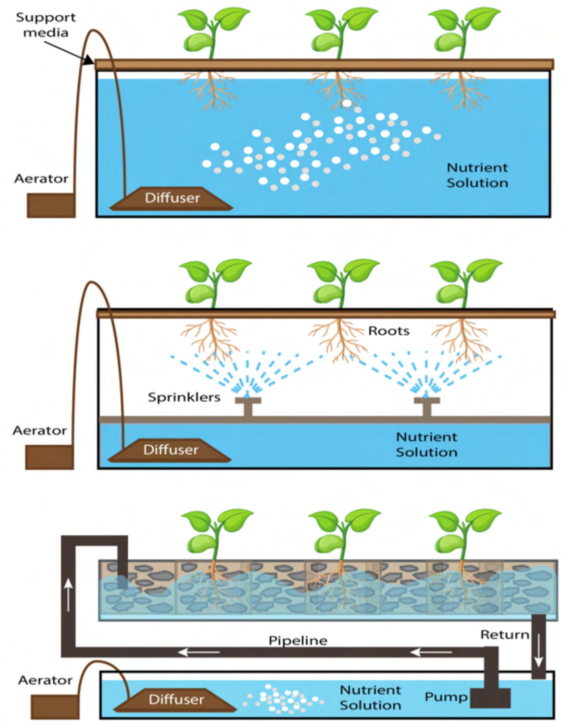

Figure 9: Differences between hydroponics (top), aeroponics (middle) and soil-based (bottom) farming [38].

plants, equals a total of 4896 plants. Every plant produces about 2.4L of oxygen per day which gives a total of about 12.000L oxygen produced from the greenhouse daily [41].

E. Heating and Temperature Regulation

For the crew to be comfortable inside the station the temperature should be around 18-25°C and have a humidity between 25-75% [42]. To provide this the station will have a Temperature and Humidity Control, THC, system. The THC will be divided into two subsystems which are the Active Thermal Control System, ATCS, and the Passive Thermal Control System, PTCS.

The ATCS will include equipment like electrical heaters, cryocoolers and thermoelectric coolers [43] and will be the active system used to keep the station at around 24°C and a humidity of 60% similar to the ISS. The humidity should be kept under 70% on the station to prevent the growth of microorganisms. The microorganisms can be harmful in many different ways. The crew can become sick if they breath in air filled with microorganisms and they can also damage the station itself. Microorganisms can lead to corrosion, make glass hard to see through, make rubber seals brittle and clog air and water filters [44].

The PTCS will be more integrated in the structure of the station and includes for example Multi-Layered Insulation, MLI, materials and blankets, tapes, paint and coatings, thermal straps, sun shields, deployable radiators, heat pipes and much more [43]. To insulate the station it will be covered with MLI blankets, which will provide protection from solar radiation and extreme temperatures. The MLI blankets are made up of mylar and dacron, the mylar is aluminized to repel solar thermal radiation and layers of dacron fabric will be placed in between the mylar sheets to keep them separated and thus prevent heat from being conducted between layers [45].

V. Ionizing Radiation

Ionizing radiation is ever present on the lunar surface which imposes constraints both on the construction of the base as well as on day to day [46]. Situated far out in the magnetosphere of the Earth, there's little protection from ionizing background radiation in the form of galactic cosmic rays (GCR), which typically has an intensity 2.6 times that of the International Space Statio (ISS) [47] [48]. The implication of this, for the crew aboard the ISS, is that their absorbed dose must be constantly monitored [49]. Once a certain threshold has been reached they must leave the station or be at a greater risk of developing cancer as a consequence of their stay [50]. GCR, although low in intensity compared to the other types of cosmic radiation, has a very high energy per particle [51]. The extent to which the proposed lunar base can negate these particles will in large define for how long one might stay and subsequently how the base is operated. The number and duration of extravehicular activities (EVAs) will also be constrained by the intensity of ionizing radiation.

A. On Luna

The three main types of ionizing radiation present on the lunar surface are solar wind plasma, solar cosmic rays (SCR) and the aforementioned galactic cosmic rays [46]. Solar wind plasma consists of ejected particles that make up a small portion of the constant radiation emitted from the sun together with, among other things, visible light [46]. SCR are particles emitted during solar flares and are thus somewhat chaotic given a short time frame but do vary periodically with high and low solar activity which in turn affect the flux of GCR [46]. Galactic cosmic rays are, unlike SCR, more akin to a constant flux. This flux is however affected locally by the activity of the sun which, in laymans terms, blows the GCR away [46]. In table II the energy per nuclei particle together with average intensity and lunar surface penetration depth are listed for the three different types of ionizing radiation. As can be seen there is an inverse relationship between energy and flux across the three different types. In order to understand the implications for human well being one must analyse the product of these two factors in terms of *absorbed dose.*

B. Tolerances

There are multiple different tolerances for effective dose that seek to balance risk with opportunity. For nuclear power plant workers, a class of workers at greater exposure, the limit is commonly set to 20 mSv/yr on average for 5 consecutive years [52]. For civilians not in a radioactive enviorment on the other hand the dose can be as low as 1 mSv [52]. There isn't much of an opportunity cost in any of these two cases as these limits are easily maintained in their given contexts. More appropriately for a lunar base one should compare it to those limits set for astronauts as they operate in a similar enviourment while also being civilians (as any military operation would be inappropriate as benchmark). Astronauts commonly experience doses of 20 to 2000 mSv during missions with 600 mSv/yr being considered a good tolerance [53] [54]. As it is hard to perceive an increased risk of cancer for low intensity ionising radiation of an effective dose less than 100 mSv/yr this could be considered a happy medium between civilian standards and that of early astronauts who realistically are taking a greater risk than lunar researchers decades later [55]

Type	Solar Wind	SCR	GCR
Nuclei energies [eV/u]	0.3 - 3 (E3)	1 - 100 (E6)	0.1 - 10 (E9)
Fluxes [protons/(cm^2 s)]	3 (E8)	0 - 10 (E6)	2 - 4
Penetration depth [m]	micrometer	centimeters	meters

Table II: Cosmic radiation regolith penetration [46].

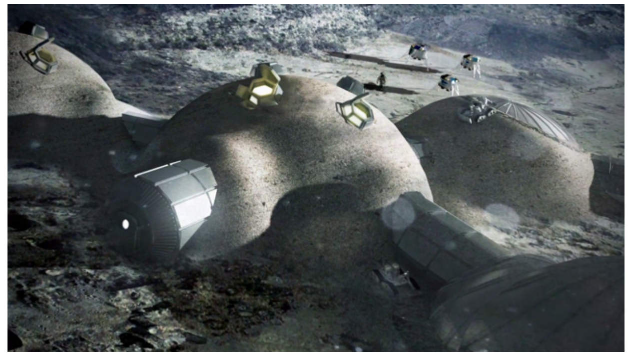

Figure 10: lunar regolith as shielding for the base [56]

C. Shielding

Having identified the types of ionizing radiation and human tolerances for them, the proposed shielding of the base as well as the EVA suit can be evaluated. The concept proposed by the Station Design group is using mainly sintered lunar regolith (see fig. 10) and possibly, to a lesser extent, exotic materials if need be. Table II shows that protecting against the two Sol associated types of ionizing radiation, those being solar wind plasma and SCR, is trivial as their energy can be dispersed in a matter of micrometers and centimeters respectively. It should also be noted that this is for regular untreated lunar regolith i.e less dense than in its sinterd state. The GCR however warrant further analysis as multiple meters of penetration means that the walls must be much thicker than what is likely to be necessary from a structural engineering standpoint, making the base itself more akin to a bunker than the analogy of the Amundsen-Scott research station. Figure 11 shows how the effective dose per year decreases as one descends further

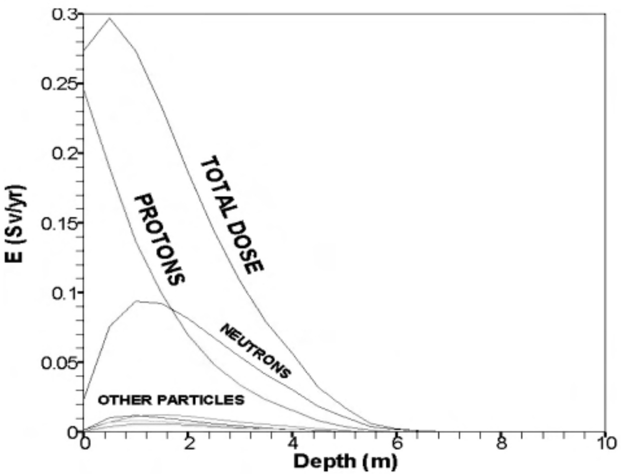

Figure 11: Effective dose vs lunar lava tube depth [57].

into the lava tubes present on Luna. It can be seen that at depths in excess of 6 meters the yearly dose falls below 10 mSv/yr. Such a low yearly dose would be ideal for the lunar base as it would enable its inhabitants to stay indefinitely, not considering other factors. Thus it is shown that, conceptually, the proposed base would be able to house a research team without ionizing radiation being the limiting factor for the duration of their stay, granted that one is able to achieve the equivalent of 6 - 7m of lunar surface depending on what level of protection one seeks. It should be noted that this equivalence must be true for 6 - 7m of lunar *surface* rather than regolith as the luanr tubes penetrate various surface layers.

As for EVA operations, table II makes it apparent that it wont be feasible to protect against all types of ionizing radiation as reaching this level of radiation protection (stopping GCR in fabric) would require nothing short of a scientific leap in the area. The Operations group has proposed using the xEMU suit (see fig. 12) for the Artemis mission which is already in development [58]. It was also suggested one might consider a portable shield for additional shielding. While such a shield protecting against sol associated particles could conceivably be made portable, it becomes a moot point as GCR makes up approximately 77% of the effective dose on Luna [48]. It goes without saying that a 6-7m thick shield would be a hassle to move about during EVA. It is made apparent that anyone undertaking major EVA operations, e.g crew during construction, must have their stay limited. Firstly assuming nominal conditions on the lunar surface, i.e no solar flares hitting the base location, the total amount of ionizing radiation is about 60 μSv/h [48]. This puts the EVA workers in a low intensity regime meaning there's no risk of acute radiation sickness [59]. Thus it becomes a matter of estimating how long one may stay before reaching the previously allotted 100 mSv/yr. Although little consideration must be made for any "Earth buffer", as the yearly amount of ionizing radiation is small (about 3 mSv) [60], one must consider the transit dose as spacecraft typically offer little protection against GCR (ISS relies on magnetosphere) [61]. Denoting our maximum yearly dose D_{max} and our transit dose D_{tr}, we can estimate (eq.1) the

Figure 12: The xEMU suit being showcased [62].

maximum allowed stay (T_{max}) for a construction crew working (exposed) 5/hr week (E_{day}) under an assumed intesity of 60 mSv/h (I_{Luna}).

$$T_{max} = \frac{D_{max} - D_{tr}}{I_{Luna} \cdot E_{day}} = \frac{100 \cdot 10^{-3} - 60 \cdot 10^{-6} \cdot 24 \cdot 10}{60 \cdot 10^{-6} \cdot 5} \approx 9\text{months} \tag{1}$$

The transit dose is estimated by assuming constant exposure to the local intensity (same as lunar surface) for a duration of 10 days, 5 days being the one way-transit time as calculated by the Logistics group. Making the assumptions stated above and using equation 1 yields a maximum stay of about 9 months. As this proved more than needed for constructing the base on time, as suggested by the Overall Coordination group, the maximum dose D_{max} can be adjusted down to 80 mSv with a resulting stay T_{max} of 7 months. Something to note is the fact that for this limit the transit to stay dose - fraction is 18% (eq. 2). This fraction would be even higher were the same assumptions to be done for a similar base on Mars, meaning the transit dose could potentially become prohibitively large, necessitating heavy GCR shielding for the spacecraft.

$$\frac{D_{tr}}{D_{max}} = \frac{60 \cdot 10^{-6} \cdot 24 \cdot 10}{80 \cdot 10^{-3}} = 18\% \tag{2}$$

VI. Non-Nominal Case

A. Virus Mutation

Exposure to non nominal levels of ionizing radiation increase the rate of virus DNA mutation which may increase the posed threat to humans. When describing this increased risk of mutation one typically speaks of the *doubling dose* i.e the does that will increase the rate of spontaneous mutation of the DNA by a factor of 2 [63]. For the human Genome this dose is estimated to about 0.2 - 2.5 Sv in a high intensity regime, meaning that one would have to be exposed to life threatening levels of radiation in order to double this rate [64]. Because of this, any increased risk of mutation of the human Genome on the lunar base is a moot point, as this level of radiation must be avoided regardless. There is, however, an inverse relationship between doubling dose and genome size [65]. Although not extensively researched, The aforementioned point gives some credence to the possibility of an increased mutation rate of viruses in an enviourment of elevated levels of ionizing radiation. Most random mutations to the genome of any organism are of neutral or detrimental effect, lowering the potency in the context of viruses [65]. There is however a non zero chance of beneficial mutation (the driver of evolution) [66]. It is thus possible for a virus to *evolve*, and the possibility for it to do so could potentially be higher on a lunar base as proposed in this project. It has been suggested that the SARS-CoV-2 virus, which caused a global pandemic in 2019, evolved through such a mechanism and that it might even be correlated a heightened GCR intensity due to low Solar activity during this time period [67]. It is thus worthwhile to consider the off-nominal scenario that a virus of the same lethally as SARS-CoV-2 were to evolve on the lunar base and how one might go about handling the outbreak.

B. Virus Outbreak

Given that the proposed lunar base, BLISS, would rely on a closed-loop life support system, it would be crucial to prevent and contain any virus outbreaks to ensure the health and safety of the crew.
If a person gets infected they would be isolated and quarantined in their personal quarters, and anyone who had close contact with them would also be quarantined. The entire base would be put on high alert, and everyone would be required to wear personal protective equipment, including masks and gloves. The medical team would closely monitor the situation and implement appropriate treatment measures to minimize the spread of the virus. Regular disinfection of common areas and equipment would also be crucial in containing the outbreak. Communication with Earth would be essential to seek additional medical support and supplies if needed.

VII. Research Areas

A. Healthcare

Effectivness of different countermeasures for the effects of lunar microgravity on the immune system, bones and muscles.

B. Life Support Systems

Closing the water loop fully and recycle 100% of the used water. Further develop farming methods to increase amount of crops per m^2.

C. Ionizing Radiation

Knowledge on the effects of sustained low level ionizing radiating (less than 100 mSv) could potentially be expanded by a permanent presence on the lunar surface. Little research has been done on the subject possibly as it is hard to find a controlled environment with a meaningful number of subject because of the nature of life long experiments and the potential hazard to human life. Such studies are typically done on the victims of accidents which entails that current knowledge is mostly confined to singular events of high fluxes of ionizing radiation. Although the ISS and such orbital stations present a better opportunity, as these typically aren't fully shielded, EVA personal conducting numerous missions on the lunar surface could prove good subjects. It could be argued that not doing so would be a wasted opportunity as it is one of the already small category of people that wilfully expose themselves to the potential increased risk to their personal health.

VIII. Discussion

A. Healthcare

Living on the Moon poses a number of challenges that need to be overcome to maintain the health and well-being of the inhabitants. However, with the use of appropriate countermeasures and technology, it is possible to mitigate these challenges and create a safe and hopefully sustainable environment for humans on the lunar surface.

B. Life Support Systems

Survival on the Moon is possible for humans in regards to air and atmosphere, water and waste. However there are still some improvements needed for self-sufficiency to be achieved, as the reliance of space food and nitrogen from Earth remains.

C. Ionizing Radiation

The analysis of ionizing radiation and it's effects is meant to be read as a rough estimate rather than a detailed analysis. Two major assumptions made by the author are a) complete shielding against Solar associated particles by lunar base and EVA suit, as well as b) Only nominal levels of Lunar radiation from *all* sources. Assumption a) is done not because it is believed that the xEMU would be able to stop all Sol associated particles (it most definitely won't) but rather that GCR dominates the absorbed dose. The implication of this is that an in depth analysis of EVA on the lunar surface would mean looking into the contribution from these particles on the overall dose as it is not to be considered an negligible amount in such a context. Assumption b) also comes with a major caveat and that is the fact that conditions on the lunar surface is subject to extreme local variance. This is especially true in the case of solar flares, an example of which is the one that struck the moon between the Apollo 16 and 17 missions [68]. Had it hit one of the two crews they would have most certainly been exposed to lethal levels of ionizing radiation. Solar forecasting and warning systems thus becomes critical if one is to stay safe on the lunar surface.

D. Cost Analysis

The cost of the life support systems like the water recovery system, the Sabatier system, the oxygen generation system and some specialised work-out equipment is estimated to be about 460 MUSD.

The initial agricultural costs are estimated to be 8 MUSD for hydroponics and 10 MUSD for aeroponics with a yearly operating cost of about 1.2 MUSD.

The MRED is estimated to cost about 5 MUSD. The Circular cycling centrifuge with some development costs included is estimated to about 3 MUSD. Similarly, it is anticipated to cost 3 MUSD to outfit two medical bays.

IX. Conclusion

Based on the information presented in this report, it is clear that the establishment of a lunar research station is a complex and multifaceted endeavor that requires careful consideration of a wide range of factors. From crew selection and healthcare to waste management and radiation protection, every aspect of the mission must be carefully planned and executed to ensure the success and well-being of the crew.
The proposed solutions for each challenge, including the use of advanced technologies and innovative approaches, demonstrate the commitment and dedication necessary to achieve self-sufficiency and sustainability in space. Ultimately, the success of this mission will depend on the careful balance of scientific exploration, technological innovation, and human factors, and the continued commitment of all stakeholders involved in the project.

A. Improvements and Future Work

The BLISS mission aims to address various challenges and proposes solutions to ensure the well-being and safety of the crew. One potential area for improvement is the development of more advanced medical care technologies, such as on-site imaging and diagnostics as well as further research be conducted on the long-term effects of lunar living on the human body, especially regarding the immune system and bone density. Ongoing research on the effects of long-duration spaceflight on the human body and mind will be crucial to improve crew selection and psychological support. Advancements in recycling systems, such as closed-loop water and air systems, could reduce reliance on resupply missions and increase the sustainability of the lunar base. Additionally, the integration of artificial intelligence and robotics into the station's systems could potentially increase efficiency and reduce the workload on crew members. These areas provide opportunities for future research and innovation in the field of space exploration.

Future work could also include expanding the scope of the mission beyond research to include commercial activities, such as space tourism or mining. As technology advances and new opportunities arise, the BLISS mission could evolve to meet new demands and challenges. As alluded to in section VIII-C, evaluating the capabilities of the xEMU suit to more precisely evaluate exposure as well as analysing local variances in flux for all types of ionizing radiation, would both be natural continuations of the work that has been presented here. Although unlikely to change the overall picture, it could become interesting from an operations point of view, were one to do a detailed analysis of day to day operations.

In summary, the BLISS mission represents a significant step towards establishing a long-term lunar base and advancing our understanding of human spaceflight. However, ongoing research and improvements will be necessary to ensure the success and sustainability of the mission in the years to come.

X. Division of Work

- Antoine: Introduction, Crew selection, Healthcare : circadian rhythm, surgery, moon dust, entertainment, pregnancy and death guidelines.
- Irene: pregnancy; death guidelines; life support systems: air revitalization, waste management;
- Lisa: Life support systems: Water Production and recycling, Food Production, Heating and Temperature Regulation
- Ruben: Ionizing radiation and virus mutation
- Fritiof: Abstract, Conclusion, Healthcare: short term, physical well being

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