Lunar Research Station

Human Aspects - Red Team

Aldric Gourrat, Alice Wallner, Barbara Girard, Edward Amoev,
Grégoire Brivary Couret
MSc students, KTH, Royal Institute of Technology, Stockholm, Sweden

***Abstract* - This paper sums up our teamwork on a Lunar Research Station, comprised of an Overall Coordination Team, Logistics Team, Station Design Team, Operations Team as well as the Human Aspects Team that is ours. The goal of this paper is to study the different human aspects which will occur on a Lunar Mission. Those aspects are crucial as they will ensure the survival of the team. Several points will be discussed : lunar environment, life support systems, physical and mental health as well as emergencies. It offers solutions on how to adapt existing facilities and systems on the International Space Station, as well as the proposition of new technologies, specific to a Lunar Mission.**

***Index Terms*—human spaceflight, lunar research base, moon exploration, human aspects of spaceflight, radiation, microgravity, EVA, ISS, LSS, health in space, nutrition, emergency systems, shielding, AxEMU, waste management**

NOMENCLATURE

ATCS	Active Thermal Control System
CFE	Colony Forming Unit
CO	Carbon Monoxide
ECLSS	Environmental Control and Life Support System
EMU	Extravehicular Mobility Unit
EVA	Extra Vehicular Activity
ISS	International Space Station
LMS	Leakage Monitory System
LSS	Life Support System
NASA	National Aeronautics and Space Administration
PPE	Personal Protective Equipment

INTRODUCTION

In the year 2037, the Artemis program has come to a successful close, meeting its objectives after some delays. Humans are now traveling to Mars. The significance of the Moon as a scientific destination has become increasingly apparent, and plans are underway to build a substantial research facility on its surface. This station will resemble the Amundsen-Scott Station in Antarctica and will have the capacity to hold up to 50 people. This project will contain necessary aspects of human habitat on the Lunar Research Station which is scheduled to begin operations in 2040.

I. ENVIRONMENT AND ATMOSPHERE

The environment on the Moon is the combination of five factors : Gravity, Radiation, Temperature, Atmosphere and Light. All these parts are not closely linked, therefore they will be treated in their own section. The global life support system is the combination of all the solutions found to adapt to this environment. It will also include the food and water management, tackled in an other part of the report.

At the end of this section, table I will sum up the needs in terms of power and money for each solution to the environmental issues.

A. Gravity

The acceleration of the gravity on the Moon is 1.62 m/s^2, which is about $\frac{1}{6}$ of the Earth's. The lack of gravity is an important issue : astronauts lose both bones and muscles mass because the body is not constraint by the gravity and can lead to osteoporosis. To stay in good physical shape, astronauts must do exercises everyday, as on the ISS [1].

It is chosen here to use the same solution as in the ISS, that is to say working everyday with 3 exercises devices such as the ergometer, treadmill and resistance exercise device. The subject will be tackled deeper in the Health Aspect section (Part III-A). No experience has been led on fractional gravity, but if the consequences are similar to micro gravity, it is possible to imagine that if the physical shape of a member of the crew is not well managed - for instance being too weak -, it would affect their return on Earth. Like radiation, the gravity could thus be a limiting factor for the duration of the mission and it has been chosen that one member could stay one year maximum on the station. The specific number of one year is chosen because astronauts stay six months in micro gravity on the ISS, and it is assumed that people can stay longer in fractional gravity.

The lack of full gravity also leads to an increased space between the vertebrae, a rounder eye, an increase of body temperature during the first days. All theses consequences must be monitored and are discussed in the Health part III-A.

B. Radiation

Radiation is due to particles coming from the Sun or deep space. When solar activity is strong, few deep space particles reach the Moon, and conversely. Radiation is mostly composed of atom nucleus, such as protons or alpha particles, neutrons, electrons and high energy photons [2].

Radiation is an important issue to tackle in the Moon colonisation as long as it is a limiting factor for the staying duration. At high dose, it has both effects on humans and devices. For instance, it causes diseases for humans, the most known is cancer, and the probability of dying from a cancer in a lunar base mission is from 0.3 to 6% [3]. Technologies damage can be of different natures : short circuit or altered performances. This is due to single event effect, differential charge or atom displacement.

High dose of radiation can happen on the Moon, due to the lack of atmosphere and magnetic field. Depending on the solar activity, the average dose on the Moon is between 110 mSV and 380 mSv and can reach in the worst cases values such as 1 Sv [4].

As the legal limit for european workers in nuclear plants is 20 mSv/year [5], there is a real need to protect the station and the crew from the radiations. Two solutions already exist : an active and a passive shield. The active shield consists in a magnetic field around the station, with enough power to reflect every charged particle. There are however two main issues. It only traps charged particle, but not neutrons for instance. It is also really demanding in power. That is why the second solution is preferred. It has been decided with the Station Design group that regolith should cover the station. The regolith shield will be around 3 meters thick [6] to prevent any radiation from coming in.

C. Temperature

The temperatures must be controlled inside the station. The human limits for living in term of temperature are between 4 and 35 °C, if the humidity is under 50% [7]. The humidity will be under this rate, as explained in Part I-D. The objective is to have around 20 °C. It is the most comfortable temperature for the crew, and if something goes wrong with the temperature regulation, being as far as possible from the temperature boundaries allows more time to react and solve the problem.

In order to design the thermal system of the station, it is mandatory to know the thermal balance, this is what is discussed in this paragraph. More assumptions need to be made. We suppose in particular that only radiation is considered as heat transfer, and most of the conduction is avoided thanks to a good insulation.

A summary of thermal interactions is presented in Fig. 1. Radiation is the only way for heat to escape so the balance of the Station is similar to the ISS and will have to be cooled as well. A heating system will be there in backup, to heat the station before the astronauts come inside, but also in case of a emergency which creates cold, such as depressurization.

Cooling the station : Controlled radiators are used to cool the station. They are basically the same as in the ATCS (Active Thermal Control system) of the ISS [8]. Controlled radiators will consist in deployable and retractable mechanism. The mass flux of liquid ammonia in the radiator will also be controlled, to manage how much heat will dissipate.

Heating the station : As said above, heating the station will be punctual as the thermal balance is comparable to the ISS one. Only heaters will be used, powered with solar panels to heat the station.

Heat transportation : The heat production and dissipation will happen at really local places. That is why a transportation system is needed. The thermal system will be the same as the ATCS in the ISS. It consists in pipes filled with water and ammonia. These pipes will go through the whole station.

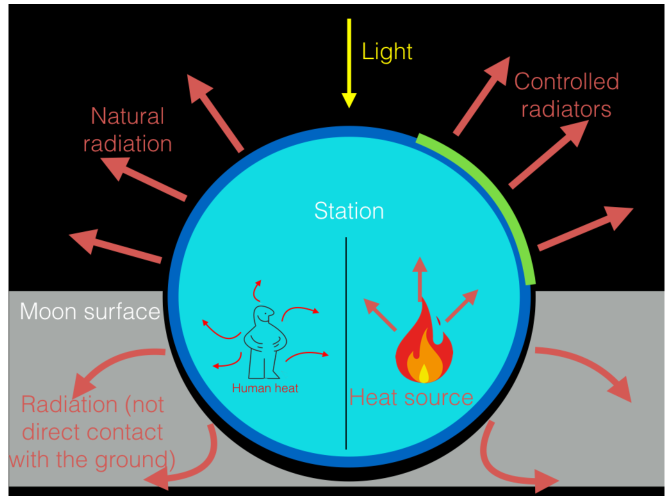

Fig. 1: Thermal interactions in the station.

Finding information about price and power consumption is quite difficult for specific systems in the ISS. A rough estimation will be performed. The costs of heat transportation, cooling and heating systems are estimated at respectively 600 000 €, 450 000€ and 300 000€. Then, there is the power needed to control the system, and it is assumed that it is low. An overestimation could be 10 kW in the worst cases. This number will be taken to be prepared for every situation.

D. Atmosphere

The atmosphere is one of the most important parts in the environment part. Few distinct points needs to be managed : the pressure, the oxygen production and carbon removal, the hazards removal. This is why each of them are tackled separately. The atmosphere in the base will contain the same molecules as the atmosphere on Earth, but not in the same quantities.

One atmosphere management system will be constituted of devices which will manage every part tackled above. Then, as the atmosphere is a critical system, the main station will have three of these devices to have redundancy to be as secure as possible. Two of the atmosphere management systems will also be in the emergency module.

1) Pressure: In the Earth's atmosphere, the pressure is maintained by nitrogen, so as in the station. However, due to mechanical constraints given by the design of the station, the atmosphere inside the station will be 0.5 atm (cf station design report [9]). With the Earth's atmosphere composition, the oxygen concentration would be too low to live a proper everyday life. More oxygen is needed and that is why it has been chosen to have 34% of oxygen in the station atmosphere, and not 21% as it is on Earth. Furthermore, the station design team decided to have some labs pressurized at 1 atm, to conduct experiments which a higher pressure. This configuration leads to two problems : how to manage the difference of pressure inside the station, and the increased risk of fire due to a a greater concentration in oxygen. The fire emergency protocols are explained in the section IV. Concerning the difference of pressure, airlocks will be installed between the places at 1 atm and those at 0.5 atm.

Having a pressure of 0.5 atm is not an issue as long as you have enough oxygen. Indeed, the Armstrong limit will not be reached. The Armstrong limit is the pressure for which water boils at 37 °C i.e. the human body temperature, and is around 0,06 atmosphere [10]. This limit is dangerous because astronauts can quickly have a loss of consciousness.

As the station is pressurized, some leakages can occur. Nitrogen is mandatory to maintain the pressure. Huge nitrogen tanks are brought from the Earth. The volume of the station is estimated at 1000 m^3, which approximately corresponds to 900kg for a 1 atm pressure. As it is assumed that only little occasional leakages occur, one tank of 900kg is brought from the Earth to compensate leakages. When the tank runs low on nitrogen, a new tank is brought from the Earth.

Such a solution is motivated because it appears as a good trade-off regarding costs. Producing nitrogen requires to have a proper system. This system would be really expensive, and would not be used a lot of time, as it is assumed that the leakages are small. As the gate between Earth and Moon is already existing, shuttles can come regularly to the station, and bringing a tank appears to be the best solution.

2) Hazard removal: The hazards in the air are every molecule or bacteria that can threaten human life. It can be water from condensation or methane from flatulence. It is planned to have charcoal filters to remove classical hazards. It is also possible to control the water in the air with the temperature [11]. As said in the paragraph related to temperature, the relative humidity should stay under 50%. These filters will help meet this requirement.

3) Oxygen and carbon dioxide recycling: As it was explained, the pressure inside the station will be half of atmospheric pressure. However, what matters about the oxygen and carbon dioxide cycle is the number of particles in the air (ppm), which is not pressure dependent.

The basic chemical reaction used in the ISS to remove the carbon dioxide is the Sabatier reaction [12].

$$CO_2 + 4H_2 \xrightarrow{400\,°C+\text{pressure}+\text{catalyst}} CH_4 + 2H_2O$$

The differential enthalpy associated to the Sabatier reaction is $\Delta H = -165$ kJ/mol, which means it is an exothermic reaction. Thanks to the technologies available in 2040, it is assumed that the excess of heat due to the reaction will be used to maintain the reaction. Thus once the reaction has started, it demands no more energy.

The reaction chosen to produce oxygen is the water electrolysis. The chemical reaction is [13] :

$$2H_2O \longrightarrow 2H_2 + O_2$$

The differential enthalpy associated is $\Delta H = 572$ kJ/mol.

Overall, the reaction for recycling CO_2 into O_2 is :

$$CO_2 + 2H_2 \longrightarrow CH_4 + O_2$$

The average consumption of an astronaut is 0.91kg, so 28.4 mol of dioxygen per day (including workout time) [14]. Considering the 50 people crew, and an efficiency of the electrolysis reaction of 0.9 (nowadays it is about 0.8, and an increase is planned in the next years), it is possible to find the power needed for recycling CO_2 into O_2. It is about 11kW.

As seen in the overall reaction, hydrogen will be needed. It is possible to find it thanks to water electrolysis again. Indeed, as the Operation Group explained [15], 2.4 tons of ice per day could be extracted. It is enough to have the hydrogen needed, and the surplus of oxygen product from electrolysis can be stored for emergencies for instance.

This is how the system which will purify the air will work.

E. Light

In order to survive, the crew needs a certain amount of light. To control the crew's health, it is assumed that all the light is provided by the spots in the station, even if it is located somewhere on the Moon with intense light exposure.

Light provides vitamin D, which is essential to survive. The average amount of exposure to natural light to get enough vitamin D is between 10 and 30 minutes per day [16], and the main risk is the vitamin D deficiency. It is forecast to have a regular day-night cycle, with at least 12h of daylight (it could be more if light needs to be turned on for logistics). Even if we choose lamps that can reproduce solar spectrum and thus getting close from the natural light, it cannot be ensured that there won't be any lack. This is why food supplements of vitamin D will be given to avoid every deficiency.

The design of the lights will be made to have a proper life : having enough light to live on the day, and having a moment without lights to simulate the night during a 24 hour cycle.

We estimate a power consumption between few Watts and a hundred of Watts, depending on what the lamp is supposed to light up. Considering all the lamps in the station, the power needed to power up all the lights is roughly between 1000 and 10 000 W. The cost estimated is around 30 000€.

F. Sum up of the costs for the environment solutions

	Power [kW]	Money [€]
Light	10	30 000
Radiation	0	Counts for station design budget
Temperature	10	1 350 000
Atmosphere	12	1 300 000

TABLE I: Power and money needed for every environmental subsystem

II. Food, Water and Waste Management

In order to survive, the crew needs to fulfill at least the basic necessities in terms of water and food. Living in a harsh environment such as the Moon could deeply affect the needs of the astronauts. However, as no data is really existing about living on the Moon for one year, some assumptions will be made and detailed progressively.

The human body can be seen as an open system (Figure 2). Nutrients and water go in and fatally, water and waste have to go out (it could be seen as a mass conservation law).

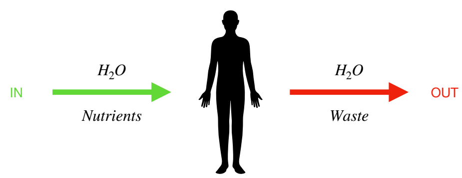

Fig. 2: The human body as an open system : its consumption and wastes

The first objective would be to know the amount of food and water that have to be daily ingested. Then, it will be important to take into account the different nutrients that one have to consume in order to avoid lacks and where it is possible to find them. Also, as this project refers to innovation and future, farming in space could be explored. Finally, the wastewater and waste managements will be treated.

A. Water

The amount of water needed for drinking and eating purposes can vary a lot depending on the sex, age, weight, etc. According to [17] and [18], it seems reasonable to take into account 2.5L per person per day. The majority of this daily amount will be directly absorbed, but a small part is dedicated to hydrate the food. In fact, as it will be mentioned in the following parts, some food will have to be imported from Earth and thus dehydrated.

The water will be stored in tanks constantly refilled by the recycling and treatment systems. In fact, some water will be imported from Earth during the really first phases but then most of the water will be taken directly from the Moon by mining it.

B. Food

To maintain a great health, a proper diet is required. In fact, the food in space has to follow several requirements. First, the daily amount of calories should be available, not only for basic surviving but also to allow the crew to fulfill their tasks. Also, the food must be healthy and has to contain the required nutrients for a daily intake. Last but not least, it seems essential to offer quality and varied food in term of taste, as it may have a great impact on the crew's mood.

1) Calories and nutrients: Before giving any data, it is important to notice that when someone is talking about "calories", it actually means kilocalories (kcal), this measure of energy can also by given in kilojoules (kJ). According to [19], the need in calories has a wide range, from 1900 to 3200 kcal. By considering a crew respecting parity and accounting a caloric expenditure slightly lower than on Earth due to lower gravity, 2400 kcal per day per person are needed.

The calories come from the macronutrients which are carbohydrates, fats and proteins. The requirement of these is about hundreds of grams. It is important that the food to be chosen contains the right amount of macros without overtaking the recommended daily allowance. Then, choosing food with high calories concentration seems interesting to tackle transportation issues due to the weight but also quite relevant in order to avoid hunger problems due to low gravity. In fact, the crew may suffer from a low appetite due to low gravity causing a feeling of fullness much quicker than on Earth.

Once the macros have been set up to provide enough energy to the crew everyday, it seems necessary to evoke the micronutrients. These are basically the vitamins and minerals, they are not responsible for the calories ingested but have an important role in the metabolism and the health of the living beings. A lack of them may have great consequences on the physical and/or mental health of the crew, causing from an excessive tiredness to cardiac problems. There are a lot of different micronutriments, most of them are listed bellow :

- Vitamins : A, C, **D**, E, K, B[1,2,3,5,6,7,9,12], Choline.
- Minerals : **Calcium**, Chromium, Copper, Iodine, Iron, Magnesium, Manganese, Molybdenum, Phosphorus, Selenium, Zinc, Potassium, Sodium, Chloride.

Regarding all these elements, the best solution in order to provide all the necessary micronutrients would be to use supplements, which are compact and not too heavy to bring. In fact, some of them are really complicated to get if not on Earth such as vitamin D. This vitamin is synthesized by the sun light on the skin which will be hard to get as much as on the Earth, and it is responsible for the quality and health of the bones by regulating the calcium rate in the body. This is only one example among many, the supplements would be a great way to regulate the nutrients precisely without too many risks of lacks or over consumption (which can be responsible for some serious diseases such as kidney stones).

2) Growing food on the Moon: To provide a sufficient amount of food without being to dependent on the cargo supplies from the ground, it would be interesting to set up a system of farming directly in the base to provide at least a certain portion of the daily amount of calories required. First of all, the type of food to grow must be selected and animals are rejected due to the higher complexity to breed animals in a closed place. They are also much more demanding in water and nutrients and they are carrying a lot of pathogens. Thus, the food grown on the Moon will be only plants.

Among all the species of plants and vegetables that have been considered, the one selected is the potato. In fact, the potato has a great nutritious value in term of calories and also a great yield. However, in order to make it viable to grow on the Moon, a really strict process will have to be followed. First, the type of potato that was selected is the Imilla Negra from Argentina, which contains the highest value of calories according to [20], with 423 kJ/100g. This would supply the crew by approximately 32% of its daily calories, by eating potato 3 times a day with 250g each meal. The other advantage of the potato is that it can be cooked in many ways, such as mashed, fried, steamed potatoes or even transformed into flour. Then, comes the problematic of the surface of growth. Indeed, the consumption of potatoes every day would require a production in the lunar base of more than 13t per year (for a crew of 50 people). Producing such a huge amount on the Moon is a great asset in terms of logistics because what is already on the base has not to be brought and 13t is not negligible. However, with a traditional farming method, the yield is about 40t per hectare (10000 m^2) which would require more than 3000 m^2, this is not viable. But other methods such as hydroponics or alternative farming method such as [21] could increase the yield to 100 kg/m^2. Accounting this latter value, the surface needed would be about 140 m^2 which represents a bit less than the surface of one stage of the lab (cf Station Design report [9]). The amount of water needed per day will be around 550 L, this seems quite high but a huge part will be recycled and the mining capability of water has been evaluated to be sufficient (cf Operations report [15]).

C. Waste

Waste water is divided in 3 categories : grey water (hygiene and condensation), yellow water (urine) and black water (fecal matter). Grey water is highly recyclable (more than 90%), yellow water is less recyclable (around 60%) and black water is not recyclable into drinking water. The system used on the ISS is the Water Recovery System, the lunar base shall be equipped in such a nearly inspired system with further upgrades. For example, it would be interesting to recover nitro derivates from the urine in order to produce some fertilizer for the potatoes.

The other wastes such as fecal matter will be sterilized using vacuum or radiations (using UV sterilization is also a possibility), the compounds resulting from these processes could be used as fertilizers for the farm. The part that cannot be recycled or used as a derivate will be stored on site and can be dropped in the atmosphere later on.

D. Requirements for food, water and potato production

Ressources	Quantity per person per day
Water	2.5L
Dried food	1kg
Potatoes	750g
Supplements	Depends on the crew member

TABLE II: Requirements for water and food supply

Production [per year]	13t
Water [per day]	550L
Surface	140m^2

TABLE III: Potato production

III. Health Aspects

A. Physical health

Planning the well-being of the crew is an important point, and this goes by making sure that they are in a good health condition. This requires to focus on every day hygiene and sleep pattern, but also on physical exercises and medical emergencies. Indeed, dealing with infectious diseases or health issues which require immediate surgery has to be carefully examined, as it can not be handled the same way at it would be on Earth.

1) Hygiene: First of all, one important aspect of physical health on the station is hygiene as it concerns the every day life. For the toilets, it has been decided to use a similar model as the ISS one. It will be easier to use it as there will be some gravity. It might not be necessary to use straps to use it. The concept of vacuuming urine and packing away faecal matter enables to reduce the amount of water needed to make the system work. Regarding the shower, the crew will be able to shower at least two days per week. 7 liters per shower will be allowed. The system of the shower will be similar as those on Earth and will use high pressure water in order to counter act the low gravity. The water will then be recycled, as detailed in the Waste and Water Management part (II-C). The other days, they will be given wash cloths as well as 1 liter of water in order to quickly wash themselves without using too much water and power. For basic hygiene tools, such as toothbrushes, combs, soap etc, each crew member will receive an individual kit that can be resupplied during the mission if needed. It will be necessary to have at least one vacuum cleaner or a similar device for hair cuts and nail cuts, to avoid any damages to the ventilation system. Regarding menstruation, the choice will be left to the people concerned, between being under birth control or having menstruation. If the choice of menstruation is made, then around 20 pads/tampons will be needed per person per cycle. For birth control, it could be either an IUD or the pill.

2) Sleep: Having a good sleep pattern is crucial for the well being of the crew. The aim is to respect 8 hours of sleep for everyone, as recommended by NASA [22]. The crew should sleep as much as possible at the same time (except for maintenance crew) to keep a good rhythm and have a similar schedule as on Earth. To simulate the circadian rhythm, light treatment will be used. Medicine like melatonin can also be taken if some people have trouble sleeping [22].

3) Exercise: The low gravity has an important impact on human health. As explained in the Environment part (I-A), it causes muscle atrophy as well as bone density loss. Indeed, muscles and bones don't have to support the body as they do on Earth. Astronauts loose in average 1% to 2% of bone density per month in space, when it is only 1% per year on Earth [23]. As a countermeasure, exercising will be mandatory. The crew will have to exercise one hour and a half to two hours per day, which is a bit less than on the ISS [24], as gravity is present. For researchers or scientists staying for a short period of time, the amount of exercise could be reduced as the consequences of gravity would be weaker. This would also allow more time for scientific work. The sport devices will mainly be the same as those used in the ISS. The crew will be able to train with four treadmills [25], four ergometers [26] and four Advanced Resistive Exercise Device (ARED) [27]. The load born by the crew members during exercises will have to be adapted for the situation on the Moon : they can bear $\frac{5}{6}$ of the weight they would have born on the ISS, if a linear relation between the weight and the value of the gravity is made.

4) Health Monitoring: First of all, to facilitate health monitoring, it could be considered to perform the selection of the crew on health criteria. It could prevent any health emergency that is possible to anticipate and avoid : appendicitis, chicken pox, allergic reaction or even wisdom teeth growth. Then, on the station, regular check-ups will be performed. Several physicians on Earth, equivalent to flight surgeons [28], will each follow ten crew members for the duration of the mission : during the training on Earth, on the Moon and then after the mission. This will help to detect if any health or medical issues can happen and prevent them as soon as possible. There will also be physicians and nurses in the station, for a more direct contact. As a prevention of any infectious disease, crew members will be quarantined on Earth for a week before launch. Finally, each person will have to know first aid gestures, in order to intervene quickly if something happens.

5) Diseases: In space travel, the immune system weakens. It can be caused by isolation, micro-biology, nutrition, radiation, ... [3]. Thus, the crew will be more prone to become ill. To detect diseases, screening tests will be available and used if there is any suspicion regarding the health condition of someone. It will be useful to identify the type of disease and administer the right treatment. In case of an infectious disease, the person will have to self-isolate in a special room and stay in quarantine for a determined amount of time, depending on the disease. Treatments for common diseases will be brought to the station regularly to anticipate any shortage. Lastly, the crew will have to be vaccinated again common infectious diseases such as the flu to reduce the risks.

6) Injuries and health issues: If any non life threatening injury happens (cut, broken bone etc), the doctors and nurses present on the station will be able to provide care with basic tools such as bandage, antiseptics, ... Medical devices such as defibrillators, ultrasound machines and ventilators will also be provided. If this is not sufficient, some more advanced tools can be printed thanks to a 3D Medical Printer. This will also enable to print a cast for example.

7) Surgery and Emergency: If an emergency occurs, it will not be possible to send back to Earth the person. Indeed, the travel time would be too long and the physical effects of the flight could be too hard on the body. That way, if a medical emergency occurs (appendicitis, important blood loss, ...) it might be required to perform a surgery and/or use a blood perfusion. In that case, a sterilized room will be used. The doctors and nurses will have to train on how to perform surgeries with less gravity than on Earth. To help the procedure, the surgeon could use acceleration compensators [29]. Surgical robots could also be used to execute surgeries, and could help the surgeon thanks to telesurgery [29]. Several robots are being developed, like the da Vinci Surgical System [30] as shown in Fig.3 and could be used. Furthermore technologies are being improved to reduce the effect of the delay of communication between the Earth and the Moon. For example, algorithms could predict the intended motion of the robotic arm so that the surgery could be efficient even with a 2 seconds delay [29].

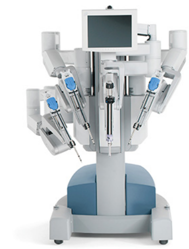

Fig. 3: The da Vinci Surgical System [31]

Lastly, anesthesia is an important point regarding surgeries. As explained in [32], it brings many challenges. It would be safer to perform regional anesthesia rather than a general one, specially if the person performing the procedure doesn't have a lot of experience. A conscious sedation and an endotracheal intubation would be recommended [32].

8) Health before and after the mission: Finally, it is important to consider how the human body will adapt to the mission. They will first have to adapt during the journey to the Moon and then for the first days in the station. Many symptoms will be encountered : fluid shift towards the head, disorientation and confusion caused by the dysfunction of the vestibular system, ... [3]. This way, the crew might not be able to perform any too exhausting tasks on the first days. Then, their body will adapt to the reduced gravity. Back on Earth, their body will have to adjust again and be closely monitored. Indeed, the sense of confusion will appear again, as well as the fluid shift but will go back to normal soon after. However, muscle atrophy and bone density loss will require more time of recovery. It will also be important to perform scientific research on the recovery, as bone loss recovery is for example not completely understood yet. Crew members could also experience ocular problems [3]. Effects of long term radiations will also have to be studied.

9) Summary of the requirements: The requirements for hygiene as well as physical health and health monitoring are summarized in Table IV and Table V.

Ressources	Quantity per person per week
Water	19L
Washcloths	14
Soap	10g
Toothpaste	3.5g

TABLE IV: Requirements for hygiene

Equipments	Quantity
Ergometer	4
Treadmill	4
ARED	4
3D Printer	2
Ultrasound machine	1
Defibrillator	3
Ventilator	3

TABLE V: Requirements for physical health and health monitoring

B. Mental health

The impact on mental health during a spaceflight that spans up to a year can not be neglected. Research about what challenges could be encountered have been executed, although most of it is based on general isolation, in places such as the Amundsen Scott station during the winter months. This does, for example, not cover issues such as not being able to abort the mission with immediate result due to the immense distance to a possible rescue. By being stationed for a longer period of time than a month or a few, some minor issues with other crew members or general existential anxiety can accumulate into such big problems that a crew member needs to be sent home, therefore interrupting the mission and jeopardizing human well-being. As said by NASA administrator, Dan Goldin, in [33];

"If we expect to send people on missions of two or three years, we darn well better deal with the psychological aspects in addition to the physiological ones. This hasn't been our tendency in the past."

There are many different scenarios to keep in mind and in order to thoroughly assess the situation it is needed to divide the challenges in subcategories. In the same article by [33], a mapping can be found of the impact on mental health a long duration spaceflight would have. Here, the author differs on what aspects are psychological, psychosocial, human factors and habitability. This investigation will assess a few main issues in each category, specifically for a mission to the moon with a longer stay. Following the assessment, there will be a section of solutions and precautions made in the planning of this mission to prevent and/or treat the issues and the consequences they might yield.

1) Psychological: Spaceflight in general means being isolated from your natural surroundings. Being on our lunar research base will make you one of only 50 people in a very confined area for a year. The possibility to go outside and have some fresh air, spend quality time with family and attend important or urgent affairs on Earth, is not within reach for a year. According to the design of the station, there will be limited possibilities for privacy, which can also be a strain on the psychological health.

Another psychological factor the people on the base need to face is the fact that an immediate rescue is very unlikely. Of course everyone will be aware of the different backup systems for life support, but accidents happen, and if they do, these people are aware that they are hundreds of thousands kilometers away from their home. This kind of experience is very rare on Earth and is something that is hard to prepare for.

2) Psychosocial: When working everyday with the same group and never really "going home" and getting a break from the people you work with, little quirks can start becoming a skew in the relationship needed for being happy at work. As stated by [34], one Russian cosmonaut who was on the Mir Station in the 1980s estimated that around 30% of the crew's time was spent on conflicts within the crew.

Poor leadership is another aspect that can cause psychosocial problems. It can mean both a very strict leadership and a very loose one - or somewhere in between with lacking communication. According to [35], a trend seen in experiments carried out in confined groups was that commanders tend to communicate less and less over time with the mission control, which could imply complications of the management onboard.

3) Human factors: The everyday, mundane part of the crew's life will be very different than on Earth. On a lunar base a lot of the everyday chores included in our free time disappears. For example getting home from work, shopping for groceries and cooking are things that will be taken care of without affecting the free-time of the crew. This will possibly create a restlessness and when the weekend comes it will be even more palpable for these individuals that the amount of indulgences are few. On the other hand, being overworked for as long as a year can cause both insomnia and a foggy brain.

4) Habitability: Without the sense of day and night, that don't naturally occur on the Moon as we are used to, it can be difficult to maintain a healthy sleeping pattern. Sounds, vibrations, temperature and privacy are all factors that can have a negative impact on the quality of a person sleep.

5) Precautions and measures: Psychological issues can be improved by having a functional mental health system on the station, meaning available therapists and good communication with the Earth. There will be two therapists on the station, working approximately 6 days per week, as most other people on the station. This will result in 1.5 h time slots for each person on the station at least every ten days. If this wouldn't be enough there are possibilities to use communication with the Earth in order to get in contact with a therapist there. The importance of having two therapists on the station is both the therapist's own health and the compatibility with the crew. There is therefore the possibility to start seeing the other therapist if they could be a better fit than the first one for a specific person. It could be argued that it would be enough to offer calls with therapists on Earth, but when taking the delay of calls from the Moon into account it would be a less than an optimal solution.

It will also be important to make an extensive psychological evaluation both before the mission and after. Before the mission the purpose will be to establish that the people coming to the lunar base are stable and in a good psychological condition. The evaluation after the mission will be in favor of the scientific research but also following up on the mental health of people who have been exposed to stress in this unusual experience. The purpose of having a functional mental health system is not only to ensure good working ethics, but to ensure that this mission does not expose people to unnecessarily tough situations that could be classified as inhumane.

As a multiple-purpose-solution, the crew will be asked to keep a journal about their everyday well-being - or lack of it. This is both for their own mental health but also to be able to draw conclusions about the mental health aspects of long duration spaceflights when they return. There has been research conducted in Antarctica thought to be applicable in longer duration space flights, but this station would be an even better subject since it is set in space with all the habitable challenges not found on Earth.

Two aspects that can have the same "solution" is isolation and work-life balance. The feeling of being isolated due to being on the Moon, on a station which you can't leave without extreme caution can't be done much about, but there are ways of distracting people from loneliness. The work-life balance is another challenge in which it is of great importance that this station can operate as a small community where you have free time and people to spend it with. This can be achieved by well thought out scheduling. The scheduling both includes every person's daily tasks but also how many people one person encounters during a day and how much free-time that overlaps with someone else's. Having this in mind, it is of great interest that the crew works at approximately the same hours so they can encounter different people than the ones they work with everyday. Although, some of the people on the base will have to work at slightly different hours than the rest, for example maintenance workers or people communicating closely with the Earth to keep the station running.

The previously mentioned 6-days workweek is thought out to be a good compromise between not being overworked but still not having enough free time to be restless. The extra workday will be compensated for, by working only 6-7 hours per day. This is both to avoid overworking but also to incorporate their intense workout schedule in their everyday tasks. Of course, this schedule will be flexible to ensure that the crew is comfortable with their workload. For instance, the researchers' schedules are the most flexible, where mainly their experiments dictate how much, how often and at what times they should work.

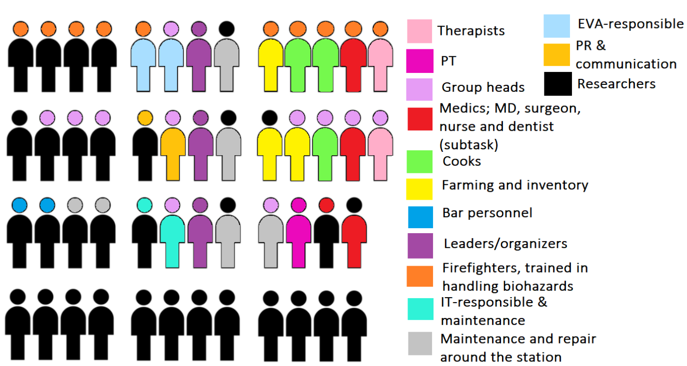

Fig. 4: A representation of the crew on our lunar research base. The body of the crew member represents their main task, their everyday work, while their head represents a subtask which should only consume a few hours per week of their time.

The organization of the station can be seen in Fig. 4. The organization of such a long term mission is important to give the crew a sense of reliability. It is therefore of great importance that there is a good leader group, an extensive medical team and good communication between the different occupation groups. To ensure this, the leader group in purple will have weekly communication with the group heads of every group, seen in light purple. As for all of the occupation groups, the rotation of people is done in a way that ensures overlapping between more experienced crew members and the new ones. The plan is for everyone to be on the station for a year to keep the rotation schedule operating smoothly. The amount of people in the different groups are somewhat based on the organization at the Amundsen Scott station during the winter months found in [36], [37].

IV. Emergency Systems

The safety of astronauts during space missions is of utmost importance, and any situation that endangers their lives must be treated as an emergency and addressed quickly. Testing materials in extreme conditions is crucial to ensure their suitability for use in space, where a confined environment can amplify risks. It's therefore imperative to carefully validate any materials intended for space use to minimize any potential hazards.

In comparison to this study, the security of ISS [38] was used to use as validation. ISS is designed with various safety systems with procedures depending on the emergency. These emergency systems would include fire detection, suppression system, contamination detection. All of the emergencies were divided into different categories, where each category was graded from a scale $1-4$ according to Fig. 5.

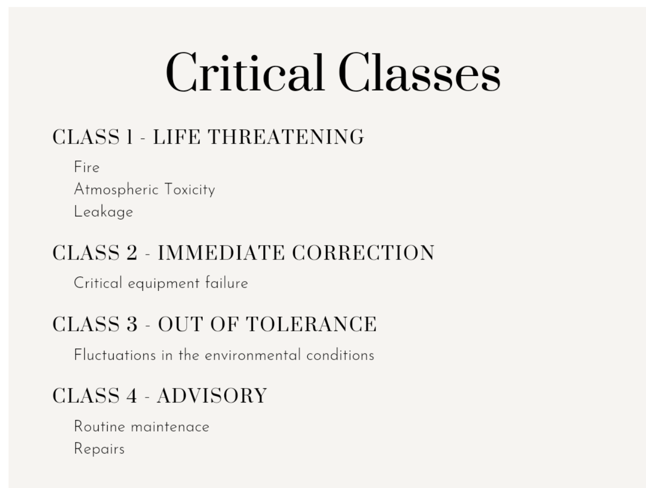

Fig. 5: Critical classes of action

When categorizing critical classes, it is crucial to consider the level of urgency required for immediate action or advisement. Class 1 encompasses life-threatening situations such as fire, atmospheric toxicity, and leakages that necessitate immediate evacuation or action. Class 2 pertains to equipment failure that is essential to life support systems, atmospheric pressurization, and the maintenance of vitals at the appropriate levels. Class 3 pertains to variations in environmental conditions such as temperature, humidity, air and water quality, which require corrective measures but may not require evacuation as urgently as class 1 or 2. Lastly, class 4 is advisory in nature and is concerned with regular routine maintenance and repairs that need to be performed at specified intervals.

1) Equipment: In order to ensure safety, it is a requirement that general equipment is readily available and easily accessible in case of emergencies. This equipment includes Personal Protective Equipment (PPE), as stated in [38], which provides all necessary protection measures. On the International Space Station (ISS), this equipment is known as the Crew Contamination Protection Kit (CCPK). The CCPK comprises:

- Goggles for eye protection
- Masks with respiratory functions
- Gloves for skin protection
- Waste bags for contaminants
- Eyewash for flushing in the event of contact with toxic materials

For a lunar base, it would also be necessary to have protective clothing available in case of toxic atmospheric conditions or when full body protection is required.

A. Atmospheric Contamination

The atmosphere on the lunar base is one of the most critical subject that should be monitored carefully. There are three different subjects that could be harmful to the crew:

- Toxic chemical contamination
- Biological contamination
- Particle contamination (lunar dust)

Due to the gravity on the moon is $\frac{1}{6}$ of that on earth, the particles behave differently in the air. It's therefore necessary that the air circulation is efficient enough and covers even areas that are heavily populated either with people or objects. In case a contamination happens, the system should be able to detect at low levels through the ventilating and filtering system (ECLSS), whilst the values are monitored through Efficiency Particulate Air system (HEPA) [38]. However, the sensitivity of detecting should not be too low or too high. If it's too low, there will be unnecessary changes in the system design, filtering, exclusion of certain materials making the project extra costly and if the limit is too high, there is a risk of acute or long term chronic risk to health. This limit should therefore be kept at a compromising level in between. Toxic chemicals in the atmosphere could be based of chemicals used in the systems, batteries, payload chemicals, operational anomalies/hardware failures such as ammonia, ethylene glycerol, fixatives and should be treated with immediate action [39]. NASA has levels for toxicological hazard where level 0 has no systematic effect if a human is exposed to less than 30 minutes and where level 4 could cause long-term effects from a short term exposure. In cases of such, evacuation is necessary where PPE should be used [40].

To prevent the risk of biological contamination, it is crucial that the levels of microorganisms do not exceed 1,640 colony-forming units per person-minute ($CFU/person-minute$) [38]. If this limit is exceeded, the system should immediately alert the crew and they should be advised to use Personal Protective Equipment (PPE) to minimize their exposure. Although crew members are constantly exposed to microorganisms, even a small amount can cause illness since their immune systems are weakened from being away from Earth's diverse bacterial environment.

Due to the lack of atmosphere on the lunar surface, the lunar dust poses a significant danger to astronauts. Lunar dust is more chemically reactive and has larger surface areas composed of sharper, more jagged edges when compared to Earth dust [41]. In order to maintain a safe environment, astronauts are required to limit their exposure to particulate matter with an aerodynamic diameter of less than 10 μm and maintain a cabin atmosphere with less than 1 mg/m^3 of such matter [38]. These measures are necessary to protect the health and safety of the astronauts as they explore the lunar environment. They can be listed as security steps, as follows:

- Sealing the lunar habitats and vehicles is crucial in preventing lunar dust from entering and causing damage to both the equipment and astronauts' health.
- Applying surface coatings on equipment, suits, and vehicles is necessary to protect them from the abrasive effects of lunar dust and to remove any accumulated dust.
- Regular cleaning of equipment, vehicles, and especially Extravehicular Activity (EVA) suits is vital in removing any dust that may have accumulated during a spacewalk.
- The use of water sprays and other dust suppression methods is essential to minimize the amount of dust kicked up during rover or astronaut movements.

Overall, these prevention methods are critical to ensure the safety of astronauts on the moon.

B. Leakage Contamination

Fluid leakage on a lunar base can pose significant risks for the astronauts living and working on the base, as well as the base's overall operation. When substances leak into a closed-loop environment, there is a high likelihood that they can spread and contaminate other areas, potentially leading to severe and compounded dangers.

In the case of a lunar base, if fluids leak and spread, they could potentially contaminate the atmosphere or other valuable resources such as water sources. Such contamination can create a domino effect of hazards, putting the astronauts' lives at risk and causing structural damage to the base. In some cases, the leaking fluids may be flammable, leading to an increased risk of fire, which could be catastrophic in the isolated and challenging lunar environment. This should be treated as a fire emergency according to IV-C.

If the atmosphere gets contaminated, a detection unit used in IV-A should detect any anomalies. If not, there should be an internal Leakage Monitoring System (LMS) that could detect change in pressure and of the internal system. If the leakage can't be localized, an Attitude Disturbance Estimation System [42] could be performed by designing the pipes in modules and pressurizing them according to 6. If there is a deviation or variation in the mass flow rate from its known values, the system will alarm the crew. This also benefits maintenance since every module can be separately accessible. Nevertheless, it is essential to design the valves and quick disconnect couplings in a way that facilitates their maintenance and repair, thereby ensuring the safety and well-being of astronauts.

Fluid systems should however use non-toxic fluid to eliminate the chance of contamination caused by leaks [38]. On ISS, ethylene glycerol which is not toxic, but can cause eye irritation was replaced with Triol, which should also be done with other fluids.

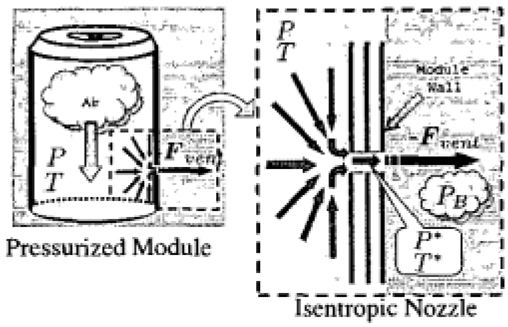

Fig. 6: Vent-hole for localizing leakage [42]

C. Fire Emergencies

Fire is a significant danger to be mindful of when undertaking space missions and can be one of the most catastrophic events since it is difficult to manage. Since smoke is a difficult hazard to escape in space, it should be kept under check. The injury doesn't only present itself by only fire, but also the inhalation of the toxic combustion that produces CO, HCN and hydrocholic acid (HCI) [38].

1) Prevention: Consequently, it is crucial to choose materials and procedures that prevent the occurrence of fire by ensuring that they have a high ignition temperature and a low combustion rate. Since the choice of materials doesn't eliminate the potential of fire, there are steps of presenting it by also controlling the oxygen pressure and levels [43]. Oxygen pressure should be kept under 30 % whilst levels should be kept in a level of 23 % if the atmosphere is enriched with O_2 [38]. This should be just enough to sustain respiration and keep down the acceleration of combustion rate.

2) Detection: In addition, fire detection systems and suppression devices play a crucial role in ensuring safety. The detection of fire is similar of that mentioned in IV-A, but by the time fire is detected by the (ECLSS) system, it might be to late. Therefore should smoke detectors be located within each bay, cabin and nearly ventilation ducts. It's of great necessity that airflow is sufficient enough, even in crowded spaces to make the smoke detectable. It's necessary that the crew is alerted in case the alarm detects CO levels above normal. The limit should therefore not exceed 5 ppm [38]. In comparison, a regular smoke detector on earth only alarms once a limit of 100 ppm is reached and kept for over 90 minutes. Since the detection system is vital for the safety of the crew, it should always be operative even if the main power system doesn't. This means that it should be connected to a secondary backup grid as well.

3) Extinguishing: If a fire is detected, prompt and decisive actions must be taken without delay, and PPE used according to IV-A. In a micro-gravity environment, it is essential to carefully choose extinguishing tools that can function effectively without the assistance of gravity. The selected approach must fulfill the requirement of not:

- Cause further combustion
- Be of toxic agents
- Become toxic when applied on fire
- Be time consuming or difficult to use

By adopting the established and proven procedures for extinguishers utilized on the ISS, two distinct types of extinguishers are currently in use. The Russian segments rely on a water foam-based extinguisher, whereas the United States Orbital Segments employ a carbon dioxide extinguisher [44]. Both of these fire extinguishers meet the requirements, presented above.
If conventional extinguishing methods fail to extinguish a fire, an alternative strategy for a lunar base is to discontinue the supply of O_2 and deplete the cabin of oxygen where the fire originated, as fire requires oxygen to persist. This should however not be performed if the crew-members aren't evacuated since they might not have had the possibility to reach a breathable apparatus. When critical situations as such occur, the crew should be able to manually override systems input data in order to open/close hatchets, or change the flow of O_2. This is also useful in case there is a power failure. After the fire has been successfully extinguished, the (ECLSS) can reinstate the cabin's air quality and purify it from harmful substances. Nevertheless, it is important to note that not all contaminants can be eliminated through filtration, and therefore a comprehensive cleansing of the cabin should be conducted to ensure a safe and habitable environment.

D. Off-nominal cases

The emergencies listed above already are off-nominal scenarios since, if the mission goes well, they should not happen. Here, two other off-nominal cases non related to the system in itself are treated.

1) Death: If an astronaut dies in space, it's considered to be an emergency and the astronauts should be prepared for handling the situation. On ISS, one of the first things that the crew will do is to notify Mission Control on Earth. They will also contact the family of the deceased astronaut, and provide them with any information they need. The crew will then work together to manage the body, which may involve storing it in a designated area until they can return to Earth or performing a space burial [45]. However, in a long-term mission to the Moon, NASA has plans to provide a special bag in which the body goes and thereafter exposed to outer space. The conditions of space will freeze the body and maintain it until a possibility of burial is provided [46].

2) Pregnancy: The best way to prevent a pregnancy is to forbid sexual intercourse in the station. However, if it does happen, the woman would have two possibilities : aborting the fetus by taking medication or going back to Earth as soon as it is logistically possible if she wants to keep the embryo. Indeed, as few research has been carried out on space pregnancies, it would not be safe to stay on the Moon. The embryo could namely be affected by the reduced gravity and the radiations. Furthermore, it would require a lot of medical technologies to perform usual medical appointments and even more logistics for the birth. Raising a child would also be very difficult and demanding in resources.

V. Extravehicular Activity

Exploration and settlement of space have long been an ambition of humanity, and the Moon has been a primary focus of this endeavor since the dawn of space age. The Moon has unique resources, such as water (ice), metals, minerals etc. that could be used to sustain future human activities beyond Earth. One critical aspect of lunar exploration however is the extravehicular activity (EVA), which involve human exploration and work outside the safe environment of the base. EVAs are necessary since no system exists that is fully autonomous and therefore needs humans to operate them. However, EVA on the Moon is different than in Earth's orbit, since the Moon presents a gravity, extreme temperatures and a presence of abrasive lunar dust.

A. Space Suit

One of the most crucial point for an EVA is the space suit. It has to provide a Life Support System, good communication, movability, ...

Since the current existing space suits are mainly for the ISS and have almost not been updated in 40 years, a new EVA suit is under development by Axiom Space [47] and can be used for the lunar research station EVAs. It it shown in Fig. 7. The space suits provided by Axiom Space will follow the same basic fundamentals with tweaks in its design to be sustainable against lunar dust and provide more mobility for example. It will have a reasonable weight, lighter than the 145kg of the EMU suit [48]. Not a lot of technical details have been released yet but it is assumed that the technical performances will be better than the EMU. That way, a primary life support of at least 7 hours can be expected, as well as more than 30 minutes in backup life support [48]. This would be enough for one day since, according to III-B5, a workday consists of 6 active hours.

Fig. 7: AxEMU : new space suit from Axiom space [49]

B. Preparation of the EVA

As on the ISS, a preparation time before going out of the lunar station is necessary. This is crucial for a smooth running of the EVA. Checking the different procedures and tools that will be used is an important point, as well as making sure that the spacesuit isn't damaged. The main point is that the body has to lower its concentration in nitrogen before donning the spacesuit, if it is assumed that the AxEMU will function the same way as the EMU for this part. The pressure being lower than the ISS one, it will take less time.

When coming back from the EVA, one of the main points is to get rid of the lunar dust. The AxEMU will be adapted to this abrasive dust but to ensure that no damage is made to the suit and the tools, the Moon Duster [50] developed by the NASA will be used. It relies on electron-beam technology.

CONCLUSION

In summary, the prospect of establishing a lunar base is within reach. Nevertheless, it necessitates meeting numerous prerequisites as crew safety is of paramount importance. Undertaking a mission spanning over a year to establish a lunar base is likely to result in both physical and psychological effects on the crew. However, in order to create a more hospitable environment for humans, taking a step forward in this direction is crucial. The majority of the necessary hardware and systems are already in existence, and only require some modification or adaptation to be utilized on the lunar surface.

DIVISION OF WORK

Aldric Gourrat

Worked on and wrote I.

Alice Wallner

Worked on and wrote III-B.

Barbara Girard

Worked on and wrote III-A, a part of V and the Abstract.

Edward Amoev

Worked on and wrote IV, the Introduction and Conclusion, as well as a part of V.

Grégoire Brivary Couret

Worked on and wrote II.

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