Human Aspects - Red Team

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***Abstract*—The mission proposed by the Red Team aims at offering satellite repair services, hence requiring astronauts to perform a wide range of more or less complex tasks. However, bringing humans on a space mission adds many requirements to both the planning and to the actual space vehicles. Using humans for the proposed servicing mission is feasible, however, the radiation doses are fairly high which limits each astronaut to a maximum of two missions. The total mass which is taken up by the systems and the consumables required to house humans on this mission is estimated to 2 200 kg, with a total volume of roughly 5 m^3.**

***Keywords*—Spaceflight, Astronauts, Life Support System (LSS), Training, Radiation**

***Sammanfattning*—Uppdraget som föreslås av det Röda laget är ett satellitunderhållsuppdrag, därav krävs astronauter för att utföra en bred mängd mer eller mindre komplexa uppgifter. På grund av valet att använda sig av astronauter försvåras dock både planeringen av uppdraget och rymdfarkosterna. Användningen av människor på detta uppdrag är rimligt men på grund av de ganska höga strålnings doserna begränsas antalet uppdrag till två per astronaut. Den totala massan som krävs av systemen för att uppehålla mänskligt liv ombord är 2 200 kg och en total volym på 5 m^3.**

List of Symbols

R	Range in g/cm^2
E_{max}	Maximum energy in MeV

Nomenclature

ACSS	Air control and supply system.
CDRS	Carbon dioxide removal system.
CO_2	Cardon dioxide.
EVA	Extravehicular activity.
GCR	Galactic cosmic rays.
GEO	Geostationary orbit.
GTO	Geosynchronous transfer orbit.
ISS	International Space Station.
JAXA	Japanese Aerospace Exploration Agency.
LEO	Low Earth orbit.
LEV	Launch and entry vehicle.
LSS	Life support system.
MSM	Mission service module.
NASA	National Aeronautics and Space Administration.
O_2	Di-oxygen.
OGS	Oxygen generation system.
SM	Storage module.
SPE	Solar particle event.
TCCS	Trace contaminant control system.
WMS	Waste management system.
WRS	Water recovery system.

I. Introduction

Manned space missions are hardly something new, humans have been in space regularly since Gagarin's first flight in 1961. However, manned missions have historically largely been demonstrations of a nations prowess or done in the name of science but with today's increased knowledge and access to technology space has become open to private companies and opened the doors for profitable space missions. In this report an overview of the human aspects of a manned commercial servicing mission to geostationary orbit (GEO) according to the work of the services team will be presented and discussed.

Bringing humans on a space mission adds a multitude of requirements which are not necessarily considered on an unmanned mission. A few differences between a manned and unmanned space mission are, the need for an earth like atmosphere on board the spacecraft, the space environment and its effects on the human body also have to be taken into account and, on top of that, humans also need metabolic consumables which is then turned into waste. These, and more requirements, have rather complex solutions and, because of the value of humans, many safety measures have to be taken e.g., all critical systems require redundancy and robustness. This additional complexity, which the presence of humans induce, is justified by the flexibility and the problem solving nature of human beings.

The following report accounts for the human aspects of an hypothetical satellite repair mission. Such mission would involve three astronauts, who would be in space for approximately 30 days. The designed spacecraft, without going into details, comprises a launch and entry vehicle (LEV) which brings the astronauts to the mission service module (MSM), which is the main living area, and the one that will contain most of the life support systems. A storage module and an airlock complete the spacecraft, the former, staying in lower orbit, is used to store the tools for the mission, and the latter is attached to the MSM for the purpose of performing EVAs. The wide range and complexity of services that can be performed during this mission makes it crucial to involve humans, and not just robots, that, at the moment, can not perform tasks with as much dexterity as an individual.

II. Method

A. Water

1) Importance of water:

Water is an essential element for human survival, health and well-being. It makes up 72% of the human body weight and is imperative for: the functionality of all cells and organs, regulation of body temperature, circulation of blood and the removal of toxins and waste. Fortunately for humans' water is the most abundant substance of Earth's surface, covering 70% of the planet's surface [1]. Producing sufficient amounts of clean water in space therefore shares the same levels of importance to sustain human life.

2) Water Generation:

Currently on the ISS, water is obtained via two principal means. Water is transported in supply tanks to the ISS via resupply space crafts from earth. While waste water produced on-board the ISS is recycled at an efficient rate to produce clean water. The current ISS US 'Water Recovery System' processes recycled clean water from the humidity (water vapour) of the on-board atmosphere, hygiene waste (hand wash/shaving/body-wash) and via purifying urine. The Water Processor Assembly (humidity/hygiene) recycles at an extremely efficient rate of 99% [2], whereas the Urine Processor Assembly, which was designed for a recovery rate of 85% water content, currently operates at a 70-75% water recovery rate due to the unforeseen with calcium sulphate precipitation (increased calcium levels in urine due to bone density loss) [3]. This loss in efficiency requires additional water to be transported via resupply ships, an increasingly expensive procedure. It is estimated to cost more than $40 000 to transport just a 2 litre bottle of water to the ISS, and currently requires a 'unmanned Russian Progress resupply ship to send up approximately $9 million worth of water every few months' [4]. Posing the importance of development in water recycling efficiency in space.

3) Technology:

For this GEO satellite mission alternative technologies and future water treating developments have been researched. The Japanese Aerospace Exploration Agency (JAXA) aims to lead the way in high-performance water recovery systems, in preparation for future human space exploration programs with their 'JAXA water recovery system' [5]. The system purifies urine at an estimated 90% efficient rate and benefits from the following technologies: An 'ion-exchange resin' to remove ions (calcium and magnesium) present in urine. Electrolysis and electrodialysis units to removed toxins at high temperature and pressure. In comparison the current US system on-board the ISS uses distillation, (evaporation and condensation) requiring large, heavy equipment and power consumption.

The JAXA WRS is expected to consume significantly less on-board volume, power, weight, maintenance time and, with the predicted 90% recovery rate, greatly reduce the mass of resupply water volume [5]. These aspects made the JAXA WRS an extremely attractive choice for this GEO sat mission, greatly reducing the volume of water wasted and re-supply needed during additional future missions.

4) Human Need::

For the GEO stationary mission the daily water usage, requirements and sources where calculated

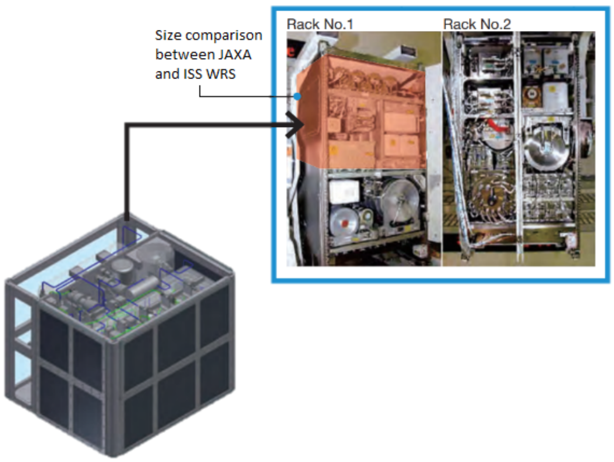

Fig. 1. JAXA WRS size comparison with current ISS WRS [5]

from the current Russian SRV-K2M Water Processor Assembly's values [6]. With a total requirement of 12.9 kgs of water per day for three astronauts, including water for the purpose of: hygiene, urinal flushing and food re-hydration. An additional 3.8 kg's of water is included for everyday of two astronaut EVA, required during the 25-day mission [7]. This is due to the additional water consumed during the additional physical demands of EVA's and the water vapour ejected from the suit due to cooling and thermal control. The total daily water requirements and sources of water for the initial 25-day mission, including the 90% efficiency JAXA water recovery system) is shown in Figure 2, and the water requirement adjustments for days of EVA shown in Figure 3.

Water required	kg/day	Source	kg/day
Drinking & Food	7.5	Grey water recycling	5.4
Oxygen	3.0	Food	1.5
Personal hygiene	1.5	Supply	3.4
Urinal flushing	0.9	Urine recycling	2.6
Total	**12.9**	**Total**	**12.9**

Fig. 2. Water requirements and supply of three crew-members per day, with 90% efficiency urine recycling rate. Based upon current SRV-K, SRV-UM ISS rates. [6]

Drinking & Food	11.3	Supply	7.2
Total	**16.7**	**Total**	**16.7**

Fig. 3. Water requirements adjustments of three crew-members per day of two man EVA. [7]

5) Water supply calculations:

The total 25 day water supply mass, including 12 assigned EVA days, 13 non-EVA days and water contingencies for 2 EVA days and 5 non-EVA days, equates to:

$$\text{Supply mass: } 13 \cdot 3.4 + 12 \cdot 7.2 = 130.6 \text{ kg} \quad (1)$$

$$\text{Contingency: } 5 \cdot 3.4 + 2 \cdot 7.2 = 31.4 \text{ kg} \quad (2)$$

$$\text{Total mission mass: } 130.6 + 31.4 = 162 \text{ kg} \quad (3)$$

This estimate does not include additional urine production and urine recycling during EVA days when additional water is being drunk. However due to some of the urine being lost during the EVA Suit Urine Collection Device (modified incontinence diaper), the estimation was kept in the simplified estimation shown (Figure 3 - as if all urine is lost during EVA). With the increased efficiency of the recycling system, a reduced the volume of supply water is needed upon further launches. As advised by the space vehicle design team, the water supply tanks will be incorporated into the interior radiation wall shielding via a number of water tanks surrounding the 'Mission module', reducing the potential radiation damage caused to the astronauts.

B. Food and Waste

1) Food:

The problem of providing tasty food which fulfils all human needs has long been a problem but also one which has been worked on for decades. Today taste might still be a problem, but an astronaut can expect a nutritious diet at work. This will of course also have to be true for proposed mission and therefore the food suggested is based on what is served to the ISS astronauts today with an addition of some extra fresh food as the mission is shorter and allows for it. Another reason for choosing to largely base the food on what is served on the ISS is that it saves on costs as less research is needed. The ISS astronauts receive about 3.3 kg of food every day [8] it is suggested to increase that slightly on the more taxing short duration mission with more EVAs and stressful work, therefore, a daily allowance of 3.8 kg of food (including packaging) is suggested this should allow for above 3 250 kcal/day for each astronaut slightly more than the 3 000 kcal/day which is provided on the ISS. As food will not be produced on board the spacecraft the total mass which will have to be brought up each mission containing food can be calculated by multiplying the number of astronauts times the mass of food they need per astronaut and day giving,

$$3 \cdot 3.8 \cdot 25 = 285 \quad \text{kg}. \tag{4}$$

In case of any emergency an extra reserve which should last for ≈ 1/3 of the mission (7 days) is added,

$$285 + 7 \cdot 3 \cdot 3.8 \approx 365 \quad \text{kg food}. \tag{5}$$

With some of the food being freeze-dried the calculated mass does not account for the mass which will be added in water. The meals will be ready to eat out of the package but for when the astronauts want a better meal there will also be a small oven on board for heating the food.

2) Waste:

The food of course becomes waste and must be disposed of in some way, historically human waste has often been vented into space but as a lot of the mission is spent in GEO, which is an important orbit, we do not want to vent a significant amount of waste in it. Therefore, all waste from both the LEV and MSM is compressed and stored. Due to the µg environment collecting human waste requires a complex system. The chosen toilet is largely based on the Space Shuttle system [9], the astronauts fasten themselves using straps to a toilet and fans create a flow which sucks the waste into tanks. The fecal waste is exposed to the vacuum of space to remove odour, kill bacteria and dry the waste for easier storage. This process does vent a small amount of gas and liquid into space but is considered negligible in comparison to the ‘pollution’ of propulsion exhaust gases. The urine is used for water recycling as is explained in Section II-A while the fecal matter is stored until re-entry. Toilets with waste collection tanks are placed in both the LEV and MSM as the astronauts will spend a considerable amount of time in these vehicles. The volume required by the toilet has been approximated to 0.5 m^2 with an extra waste tank the total volume required can be approximated as 1 m^2 this allows for both the human waste and other waste from packaging etc. The total mass of each waste management system is roughly estimated to 100 kg based on data from [9].

C. Cabin Air Control

1) Oxygen Generation:

There is a saying that human beings can live three weeks without food, three days without water, and three minutes without air. It hence seems crucial to have a robust and reliable oxygen production system, in order to provide the crew with oxygen continuously, since there is naturally no air in space. There are different strategies that exist, to either produce it or bring it and store it, but the latter might be sometimes considered more dangerous as pure oxygen is highly flammable. That is why we chose to investigate systems that enable the production of oxygen, which has the advantage of increasing the self-sufficiency of the life support system on board.

a) Human Need:

The vehicle and the mission are designed for three astronauts. We know that an average human at rest inhales about 7 to 8L of air per minute [10], the inhaled air is 20% oxygen, and the exhaled air is about 15% oxygen, so overall, only 5% of the inhaled volume is consumed oxygen. In the end, 3 astronauts will consume an average of 63L to 72L of oxygen per hour. These values are increased in case of heavy exercise, but, as it will be later presented, we did not plan to have the astronaut perform such kind of exercises.

b) Main system – Elektron Oxygen Generator: To provide for the oxygen needs of the crew, we investigated the Russian oxygen generator, which was used on the Mir space station, and is now used as a backup on ISS. Elektron is an oxygen generator that provides unlimited quantity of oxygen, using the process of water electrolysis. The principle of electrolysis is as following [11]:

Two electrodes are plunged in a mixture of water and an alkali, which support ionisation and increases conductivity (KOH = K+ + OH-, a concentration of approximately 30% maximises conduction). At the anode, negative ion OH- migrate towards the anode and discharge, releasing electrons:

$$4OH^{-} - 4e^{-} = 2H_2O + O_2 \quad (6)$$

, also releasing oxygen and forming water; while water molecules combine with the hydroxyl molecules, migrate to the cathode, oxidise, and release hydrogen:

$$2H_2O + 2e^{-} = 2OH^{-} + H_2 \quad (7)$$

The overall reaction is:

$$2H_2O = O_2 + 2H_2 \quad (8)$$

The Elektron unit comprises 12 electrolysis cells, and the degradation of 1kg of water yields 25L of oxygen per hour. To meet the requirements of the crew, 3kg of water need to be degraded, and the process consumes approximately 1kW of power. In terms of technical specifications, the Elektron unit weight approximately 150kg, and roughly occupies the volume of an individual (0.1m3).

c) Backup system – Vika Oxygen Generator: Oxygen is a key system, and there needs to be a backup system. We chose to consider the use of oxygen candles, as they do not rely on power consumption, and could still be used in case of a power shutdown, while the electron unit wouldn't be working any longer. The Vika system is a solid-fuel oxygen generator, it is fed with replaceable cartridges, also called Vika modules, that contains lithium perchlorate. An igniter can be triggered, which burns iron powder and produce enough heat to break down the lithium perchlorate into oxygen. A Vika module contains approximately 1L of lithium perchlorate, which releases 600L of oxygen when burning (enough for an astronaut for a day). Before being released, the air is cooled down and filtered to remove dust, and directly released into the cabin.

2) CO_2 Removal:

A person produces about 1 kg of CO_2 per day, and this gas is lethal for humans if its concentration is too high. On Earth, natural convection does the job for us and there is no need to care about its removal. In space CO_2 removal is necessary after a few hours of flight, which means that a CO_2 removal device is necessary in every module in which humans will spend their time. Generally, there are fans in each of the modules which suck the air out of the cabin, and then the air must be brought to CO_2 removal devices. These devices are of two types : the regenerative processes and the non-regenerative processes.

a) Non-regenerative processes :

Non-regenerative processes are called so because they generally use an additional substance to get rid of CO_2 and the CO_2 is not recycled (or at least most of it). An example of these devices is the Lithium hydroxide system which was used mainly by the Americans during earlier human spaceflights and is now the safety backup in the American modules of the International Space Station (ISS) [12]. This system uses Lithium hydroxide to remove CO_2 via the process : $2LiOH + CO_2 \rightarrow Li_2CO_3 + H_2O$. From 1 kg of LiOH and 1 kg of CO_2, one can produce about 0.4 kg of water thanks to this system. For our crew of 3 astronauts, we would need about 3 kg of Lithium hydroxide per day, which makes about 90 kg for a mission of 1 month. We would have to bring this at each mission, therefore it would be better to recycle the CO_2 thanks to a regenerative process.

b) Regenerative processes :

For long missions (more than 10 days), it is better to use a regenerative process to remove CO_2 from a station. The most known and used of these devices is the Sabatier reactor. As can be seen in the figure below, the principle is the following [12]:

- the air is first dried,
- dry air goes to a molecular sieve which adsorbs CO_2,
- clean air goes back in the module,
- the CO_2 is used in the Sabatier reactor to produce water and methane,
- methane can then either be used as a propellant or goes to a pyrolysis process to produce water and carbon.

The main advantage of such a system is that it can produce a lot of water from CO_2 : between 3.5 and 5.5 kg of water can be produced with 1 kg of CO_2. The weight of this system is about 60 kg.

Therefore our plan to implement CO_2 removal devices in the station is :

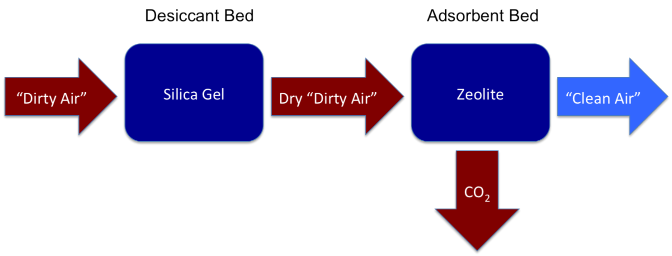

Fig. 4. Illustration of the CO_2 removal device [13]

- In the Mission Module : a Sabatier reactor and a Lithium hydroxide system as a backup,
- in the storage module : no CO_2 removal device (since astronauts will not have to go there for a long time),
- in the Launch Entry Vehicle (LEV) : a Lithium hydroxide system.

3) *Air Control and Supply System:*

a) *Cabin atmosphere:*

The cabin, similarly, to ISS, is filled with an earth-like atmosphere, 80% nitrogen and 20% oxygen, and pressurised at 760 mmHg.

b) *Air supply:*

The main and backup oxygen generation systems are located in the service module, which is the main living area of the spacecraft. The oxygen produced by the Elektron is stored cryogenically in tanks, alongside with the hydrogen, which is fed to the Sabatier reactor. Another set of oxygen and nitrogen tanks are located near the airlock for repressurising it. The air supply system includes [14]:

- High-pressure oxygen and nitrogen lines, in order to transport between the Elektron unit and the tanks located near the airlock
- Low-pressure oxygen and nitrogen distribution lines, to transport breathable air to the rest of the spacecraft
- Fans to vent air in the spacecraft

c) *Pressure Control:*

The pressure control system includes:

- Pressure sensors throughout the vehicle to monitor the pressure of the cabin
- A Depressurisation Pump Assembly and additional outlet lines for the airlock
- Manual pressure equalisation valves to reduce the pressure differential across the hatch prior to opening it

In case of depressurisation of the cabin, carry-on oxygen bottles and oxygen masks can be found in the MSM and the LEV.

4) *Temperature and humidity control:*

Temperature and humidity are important factors when it comes to the health and well being of astronauts, but also for the hardware (prevention of the development of fungi).

The temperature and humidity control system consists of , to simplify, a fan group, a condensation heat exchanger (CHE), and a temperature control cell value (TCCV), as is illustrated on Figure 5. The air is fanned out of the cabin through the fan group, sensors evaluate the difference between the actual and the expected temperature of the air, and regulate the opening degree of the TCCV. The air flux between the bypass leg and the condensation heat exchanger is determined by that degree of opening. The air in the CHE is cooled and dehumidified, before being mixed with the air from the bypass leg and released in the cabin.

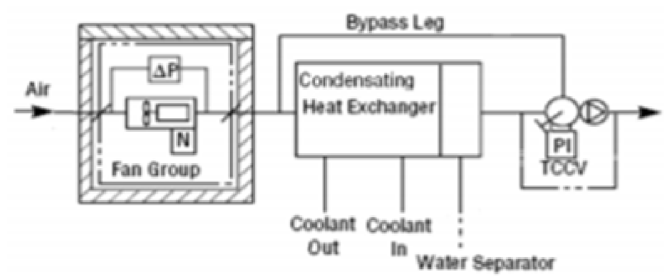

Fig. 5. Illustration of the Temperature and Humidity Control system [15]

5) *Trace Contaminant Control System:*

The air in the vehicle is in a close loop, no air is brought from the outside, and no air is released. In such cases, it is important to ensure that no chemical substance potentially health-threatening is present in the atmosphere. For that, the Trace Contaminant Control System (TCCS) is used on board the spacecraft. The system works in coupling with the carbon dioxide removal. As the air is fanned out of the cabin, it passes through the TCCS, which consists of several sieves [16]:

- A Charcoal Bed Assembly (CBA), which remove most of the chemicals by adsorption

- A thermal Catalytic Oxidiser Assembly (COA), which oxidises the poorly adsorbed components, such as methane or carbon monoxide
- A post-Sorbent Bed Assembly (SBA), which convert methane and carbon monoxide to CO2

According to NASA estimations per crew member (CM) [17], this system, for 3 astronauts, would have the following technical specifications:

- 60kg (20kg/CM)
- $0.45m^3$ ($0.15m^3$/CM)
- 0.015kW of power for the functioning of the system (0.05kW/CM)
- 0.015kW of power for the cooling of the system (0.05kW/CM)

D. Fire Detection and Suppression

Fire is an important danger in space since several humans are confined in a small environment without the ability to get out. Furthermore, in spacecrafts O_2 concentration is generally higher than on Earth and as a consequence materials are more flammable. Therefore, fire detection and suppression should be efficiently prepared in a space station.

a) Detection:
Detection can be performed by astronauts but there should also be some sensors in the space station. These sensors are mainly located in air ducts since there is almost no convection in microgravity in the cabin. There are several types of sensors that can be used, for instance : thermistors, ultraviolet detectors (Skylab), ionisation detectors (Shuttle and Spacelab), photoelectric sensors (the U.S. section of the ISS) and optical sensors (Mir and the Russian section of the ISS) [12].

b) Suppression:
There are different options in case of a fire in a station : depressurisation, water extinguishers, chemical extinguishers and CO_2 extinguishers. However, the depressurisation solution is quite extreme and also dangerous so we will try to avoid having to do it. There is a procedure in case of a fire which comes from the ISS [12]:

- Power must be removed to the affected location in order to remove ignition sources,
- the ventilation system is then turned off to stop airflow within the module and any air exchange between modules,
- atmospheric pressure control is also turned off to prevent the introduction of oxygen and nitrogen into the module,
- the crew then uses a fire extinguisher to suppress the fire.

E. Radiation

One of the main limiting factors of a human mission beyond LEO is the radiation environment. While no reliable method of estimating the accurate radiation dose in space exists, at least a rough estimation had to be made in order to be sure about the mission's duration limitations, which orbits are the most optimal to settle in and if EVA's could be performed. To do that, first, most significant sources of radiation had to be defined.

1) Radiation environment:

a) Van Allen radiation belts:
Van Allen belts consist of trapped charged particles, in particular electrons and protons, which are held in toroidal radiation belts by the Earth's magnetic field. Since these are not uniform, an inner and outer Van Allen belts are distinguished. The former extends from an altitude of 1000 km to 6000 km above the Earth and contains high concentrations of electrons and high energy protons. The outer belt consists mainly of electrons. It is more irregular than the inner belt as it is more easily influenced by solar activity but it typically spans from 13 000 to 60 000 km above the Earth's surface. The particle environment in Van Allen radiation belts with their intensity and energies can be seen in Figure 6.

As evident in the shown figure, trapped protons, which are by an order of magnitude more energetic than electrons, and, at the same time, more dangerous for humans and spacecraft electronics, are present only in the inner Van Allen belt. Therefore, as for the total radiation dose during the GEO satellite servicing mission, it was important to make sure the LEV passes this region as fast as possible.

b) Solar particle events:
Solar particle events (SPEs) are bursts of particles accelerated by the Sun. These consist primarily of protons. SPEs occur relatively rarely and can produce extremely high radiation levels since these

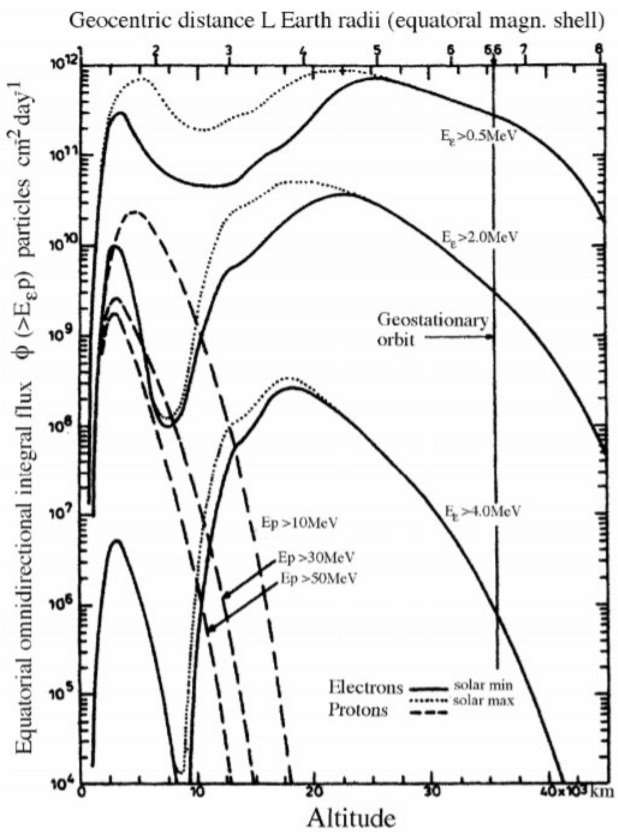

Fig. 6. The Earth's trapped electron and proton radial average flux profiles as a function of altitude [18].

protons gain even more energy than ones in the inner Van Allen belt [19]. Without thick shielding, SPEs are sufficiently strong to cause acute radiation poisoning and death for astronauts. Fortunately, the emitted particles do not travel at the speed of light and when an SPE occurs, they can be spotted and warned about at least 12 hours before it reaches Earth. Consequently, the project spacecraft was not designed to shield astronauts from a mass coronal ejection but if it happens, the mission abort plan, which is sending the crew module to lower and safer orbits, would be performed. Moreover, to reduce the risk even further, missions could be conducted during solar minimum years.

c) Galactic Cosmic Rays:

Galactic cosmic rays (GCRs) mainly consist of high energy proton, helium and other high energy nuclei. Heavy ions, energy protons and helium particles are highly ionising forms of radiation, which produce distinct biological damage. Luckily, the heliospheric magnetic field deflects most of the cosmic rays and when comparing to Van Allen or solar particle radiation, the dose from GCRs becomes negligible.

2) Radiation effects on humans:

Lowered immunity experienced by astronauts is mainly contributed by the damage of lymphocytes, which is linked to higher levels of radiation. It can also cause a higher incidence of clouding of the lens of the eye, or cataracts, and accelerate the onset of Alzheimer's disease. But most importantly, high radiation dose significantly increases the chances of cancer over the lifetime of an astronaut.

However, all these effects and their magnitude also depend on the type of radiation. In order to get the equivalent dose, which represents the health effects on the human body, a sensor measured radiation absorbed dose has to be multiplied by a quality factor characteristic of the radiation which depends on the radiation particle type. These can be numerous, but for the GEO satellite service project only 2 different particle environments were accounted for – the proton and the electron, or beta particle environment. The weighting factor for these and other types of radiation can be found in Figure 7.

Radiation	W_R
Photons (e.g., X-rays, gamma rays)	1
Beta particles	1
Neutrons	
$<$10 keV	5
$>$10 keV–100 keV	10
$>$100 keV–2 Mev	20
$>$2 MeV–20 MeV	10
$>$20 MeV	5
Protons $>$2 MeV	5
Alpha particles, heavy nuclei	20

Fig. 7. Radiation weighting factors [12].

3) Shielding:

There are many possible radiation mitigation techniques such as simply putting material between the outside and living space or active shielding that involves the generation of an electromagnetic field to deflect or capture the incoming radiation particles. However, the latter technique has many practical and technical difficulties with implementing such a method of defence, not counting the fact that it was never tested in space before. For these reasons, conventional radiation shielding was used for the mission.

Any material can act as shielding against radiation if used in sufficient amounts. A particle range in a matter as a function of its energy can be easily calculated with the empirical formula:

$$R \text{ [g/cm}^2\text{]} = \frac{E_{max}}{2} \tag{9}$$

It can be seen that the shielding effectiveness only depends on used material's areal density, therefore any substance already used for the mission could be implemented to the spacecraft's shield. It was decided that a combination of aluminium which is already required to support the spacecraft's structure and water which will be consumed by astronauts would be sufficient to protect humans from severe cosmic radiation.

4) Radiation dose:

Knowing the most important radiation sources and what kind of shielding should be used for the mission, an approximate radiation dosage could be found. To do that, some charged particle environment model for the calculations had to be used.

a) Radiation model:

In 2003, an experimental communication satellite GSAT-2 was launched first in Geosynchronous Transfer Orbit (GTO) and then stayed in GEO measuring the accumulated radiation dose with 4 differently shielded dosimeters [20]. Radiation dosage values for every shielding thickness were extrapolated from the mission's results while also considering particle type when multiplying measured values by the weighting factors shown in Figure 7. Moreover, dosage for 2 passes through the inner Van Allen belt for the project mission could be estimated from the data collected during GSAT-2's initial orbiting in GTO which lasted for 2 days. The weighting factor of 5 from the Figure 7 was used for this mission leg since the trapped protons are more prominent in such an environment. Finally, radiation dose during EVAs was calculated after factoring in areal density of a current NASA's space suit.

b) Calculated dose:

As a reference point to the desired dosage values, NASA's astronaut career radiation exposure limits were used which are shown in Figure 8. The career equivalent dose limit is based upon a maximum 3% lifetime excess risk of cancer mortality.

Career Exposure Limits for NASA Astronauts by Age and Gender*				
Age (years)	25	35	45	55
Male	1.50 Sv	2.50 Sv	3.25 Sv	4.00 Sv
Female	1.00 Sv	1.75 Sv	2.50 Sv	3.00 Sv

Fig. 8. Career exposure limits for NASA astronauts by age and gender [21].

After calculating the radiation doses for all the different parts of the mission, the total radiation dose value for the mission per astronaut was estimated which is presented in Figure 9. Apart from all of the mentioned assumptions, the maximum number of EVAs for one astronaut was set to 6 which represents the worst-case scenario. Also, the mission duration was established to be 25 days.

# of missions per astronaut	Dose per transfer to GEO, Sv	# of transfers	Dose per 1 month in orbit, Sv	# of months	Dose per 8h EVA, Sv (standard space suit shielding)	# of EVAs per astronaut	Total dose, Sv
1	0.03	2	0.86	0.83	0.11	6	1.46

Fig. 9. Estimated total equivalent radiation dose for the project's mission.

When comparing the calculated exposure to NASA's career limits, assuming the same policy is adhered to, younger astronauts could be sent to such mission only once. However, knowing the astronaut selection criteria of being from 30 to 55 years old, all of the trained astronauts should be able to perform two or more missions to GEO depending on the assessment of the dose they received after coming back to Earth. It could vary depending on the solar activity during the operation in space, the number of needed EVAs or a new spacesuit technology.

F. Astronaut Aspects

1) Medical concerns:

Medical issues in space are present, and since this is an enclosed space, they have to be dealt with on board, without the direct intervention of an healthcare professional.

a) Off-nominal medical issues:

Typical common medical conditions in space include:

- Muscular pain
- Minor injuries
- Fatigue

- Psychological issues
- Motion sickness

In order to deal with these conditions, the MSM and the LEV are furnished with medical kits, besides the crew is trained to provide basic medical care (stitches, teeth removal, injections...). The kit includes a first aid kit, a book of medical conditions and medical equipment such as defibrillator or an ultrasound machine. To further ensure the health of the crew, a team of health care experts of Earth constantly monitor their vitals, and can provide quick diagnosis and instructions when a medical issue arises.

b) Weightlessness:

Other medical conditions are specific to the space environment, and since radiations has already been discussed previously, we will focus on weightlessness.
Weightlessness is the absence of gravity, or the presence of a very low gravity, hence we prefer to use the term microgravity. Microgravity has a very special effect on the human body, because of the absence of hydrostatic gradient within the body (which is induced by gravity on earth), the blood, that pools in the lower limbs on earth, tends to migrate toward the upper body. This excess of blood in the chest causes cardiac sensors to be stretched and activated, thus inducing a physiological diuresis, and eventually a blood plasma loss of about 15% [22]. In addition to this phenomenon, the lack of physical activity leads to a loss of muscle mass, and general strength, and bone density also tends to decrease because of the lack of loading.

c) Physical activity as a countermeasure:

The main known countermeasure to the effects of weightlessness on the body is physical exercise. However, the effects are much less present on short duration flights (less than 30 months), and physical exercise might not be necessary in such missions [23]. However, we believe that physical exercise also has psychological benefits for the astronauts, and having available devices may be beneficial. Physical exercise devices in space are often voluminous and heavy, and since we have only limited space, we would like to choose efficient training devices. Hence we chose to study the device Miniature Exercise Device MED-2, as can be observed on Figure 10.

Fig. 10. Miniature Exercise Device MED-2

This device weights only 30kg, is roughly the size of a backpack, and enables the astronauts to train all weightlessness-affected muscles.

2) Astronaut Selection and Preparation:

As stated in the overall management and service reports, our GEO Station Mission will require the selection and preparation of approximately 9 astronauts for the initial year of operation, 3 astronauts per missions, 2 missions per astronauts, 5 missions per year. The radiation limits for our astronauts in the GEO stationary environments, results in a short astronaut career and fast training turn-around. Requiring a continuous preparation and training process for subsequent years. This selection and preparation process is a full time, extensive accelerated astronaut training program condensed into 24 months. It's based off the ESA astronaut recruitment and training program [24], and is explained as follows:

a) Astronaut candidate basic qualification requirements:

- University Degree (Engineering, medicine, science) or Several years of flight piloting experience.
- Excellent command of English
- Preferred age range: 30-55
- Strong cognitive, mental and social skills
- Good health conditions. [24]

b) Selection process:

- Online application
- Cognitive ability test
- Psychological Personality Test

- Medical Examination
- Professional Interview
- Fully Qualified Candidates for selection reserve

c) Preparation:
The training process will differ in some aspects to the generic ISS training flow due to the 'fast training turn-around'. The accelerated program is proposed based upon the ability to reduce the extent of training aspects. A table describing which elements will be removed and which elements will be stressed is given below (Figure 10). Allowing a reduction in total training time to 24 months.

Training blocks removed	Training blocks included
Reduced training in engineering and science	Leadership/Teamwork building
Space and ISS history	Robotics
Russian	Specialised tools required
Tours and training of ISS partner facilities	EVA skills
PR and medical skills	Core systems & maintenance
Extreme environment missions	Emergency and Off-nominal cases
On-board modules and maintenance.	Spacecraft module
Visiting vehicles & payloads.	Microgravity environment and affects

Fig. 11. Training blocks of accelerated training program, included and excluded. [24]

Due to the nature of the mission and operations, a focus on robotics, EVA and tools is required. Leadership and teamwork building robots, basic engineering and science training and microgravity environments are some examples of the training blocks included in the 'Pre-assignment training' and more specific modules are included in the 'Mission Specific Training' e.g. Specialised tools, EVA skills and Emergency and Off-nominal cases. A basic flow diagram of the training program has been included below.

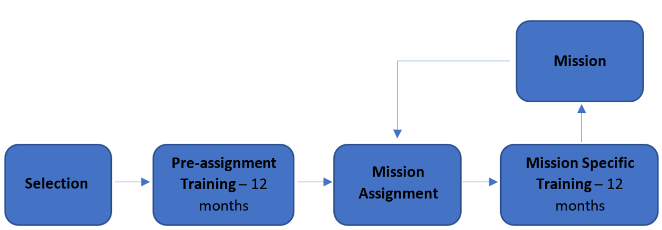

Fig. 12. Accelerated Astronaut training schedule and flow. [24]

G. Off-nominal situation : When an EVA goes wrong

We will study the case of a failure of the cooling pump in an astronaut's space suit during an EVA. It already happened in 1984 to Russian cosmonaut Vladimir Soloviov while he was repairing the Salyut 7 propulsion system together with Leonid Kizim. In that case, do we need to abort the EVA ?

Actually we would follow the same procedure as Soloviov did : first the astronaut has to power on its main and backup fans in order to cool off more efficiently. He would also do some rest periods during his EVA. However, if his temperature goes too high despite these measures, the EVA would have to be aborted and the 2 astronauts should go back to the module (it is considered too dangerous to let only one astronaut in an EVA). In any case, it is likely that another EVA will have to be performed because of the time lost.

III. Results

In this section, we will focus on summarising the mass budget of our systems on board.

A. LSS Hardware

In the hardware are included all the systems from the LSS and their redundancies/backups.

Table 1: Mass volume and power estimations of the LSS hardware. Power includes functioning and cooling. Volume and power estimations were estimated using NASA per crew member estimations [17] when no figures were available for the chosen systems.

System	Mass(kg)	Volume(m^3)	Power(kW)
WRS	650	1.2	0.01
WMS	310	1.5	0.1
OGS	300	0.2	1.35
ACSS	150	0.8	–
CDRS	100	0.45	0.02
TCCS	60	0.45	0.3
Total	**1 570**	**4.6**	**1.78**

Water recovery systems (WRS) includes the JAXA system and the water tanks. Waste management system (WMS) includes three wastes tanks (LEV, MSM, SM) and two toilets (LEV, MSM). Oxygen generation systems include the main and the backup oxygen generators. Air control and supply (ACSS) includes mainly the oxygen and nitrogen tanks. CO_2 removal systems (CDRS) includes the sabatier reactor and the backup system. Trace contaminant control system includes the main 3-beds system.

B. Consumables

The main source of consumables is water and food. The following numbers account for one mission for three astronauts.

Table 2: Mass budget of the consumables

Consumable	Mass(kg)
Water	162
Food	365
Total	**527**

C. Additional material and equipment

This mass budget includes the additional material or equipment, such has the medical kits, training devices...

Table 3: Mass budget of additional material

Material	Mass(kg)
Training devices	60
Medical kits	30
Personal items	15
Total	**105**

IV. Discussion

Using humans for the proposed mission is feasible and requires an acceptable amount of extra mass an volume which can be incorporated in the space vehicle design. One of the most limiting factors is the radiation, therefore, it would be interesting to see if any major steps are taken in radiation shielding which could allow more missions per astronaut.

A. Closed Versus Open Life support systems

The suggested LSS are somewhat closed as a lot of the water is recycled together with the oxygen, the extra weight of these systems is justified as the MSM and SM both stay in orbit and do not need to be launched for every mission. Food and waste is not recycled at all due to the lack of technology which does not make it efficient economically or mass wise. With future technology it is possible that the human waste could be used in some way, e.g., it could be used to provide energy which would increase the efficiency of the up-mass.

B. Oxygen candles risks

We chose to select as a backup system the use of oxygen candles, which work with ignited iron power that produces a lot of heat. Such temperatures (600°C) can ba hazardous, and caused, for example, a Vika canister to catch fire on Mir in 1997. That's why it's only used as a backup to the Elektron device. One might argue that a second Elektron device could be brought as a backup for the first one, however, oxygen candles to not require power, and oxygen could still be provided to the crew in case of power anomaly.

C. Systems suitable for three astronauts

For most of the system, we didn't seek to design the most fitted and adapted systems for the need of the mission, but rather focused on already-existing systems that were suitable for three astronauts. We realise that, in a few decades, more advanced technologies will be available, more adapted to the type of mission this project is aiming at. (For example, most of the systems are present on ISS, they are long-stays oriented, while our mission is only on a short-stays scale, and some of these systems might need some adjustments).

V. Conclusions

This report has given an overview of the different systems that need to be considered when sending humans to space for a 'short' stay. Such a mission, that far from the Earth's surface, raises a yet-not-well-understood concern, which is radiations, and seems to be a limiting factor with the current knowledge and technology.

Although the systems required for manning the mission are complex and add to both the mass and power budget of the entire mission it is still using current technology feasible to do especially when a large amount of the mass is only launched once.

Now, we only considered already-existing technology, but the next decades might pave the way for brand-new technologies that will ensure a safer and more reliable environment for humans. Similar missions will most likely occur in the future, due to the real need that satellites repair represent, and these missions will probably help design better LSS for humans in GEO.

VI. Division of work

Tugdual Adam: Oxygen generation, Air supply and control, Humidity and temperature control, Trace contaminants control system, medical aspects, results;
Lukas Jakas: Radiation aspect;
Julien Sparfel: CO_2 Removal, Fire Detection and Suppression, Off-nominal situation;
David Mainwaring: Food and Waste
Frederick Wilkins: Water, Astronaut Selection and Preparation

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