Exhaltra

"Even in space, a single leaf carries hope for humanity."

Acknowledgement

Members of our team, Exhaltra, are newcomers to the space settlement contest, and we consider ourselves extremely lucky to be a part of this prestigious scientific journey.

Firstly, we want to thank our Parents for their indispensable support and encouragement during the whole process. We are also grateful to the organisers of the event for providing us with such a great opportunity to demonstrate our skills and ideas.

It would be our honour to thank our coordinator, Sir, Mr Ram Naresh, for giving us the chance to participate in such an extraordinary competition. We would also like to thank our Principal, Mr Uma Mahshwar Rao, who was the guiding pillar of our dream project, Exhaltra.

In addition, we thank and appreciate the rest of the faculty members who were always there to support us and encourage us throughout the project and provide us with their valuable and insightful advice.

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1. Executive Summary:

Exhaltra is humanity's initial large-scale space habitat, a permanent deep-space settlement that orbits close to Ceres in the Asteroid Belt. It supports 15,000 people in a self-sufficient ecosystem. By harnessing the metal-rich area's resources, Exhaltra is a milestone in the evolution of human life beyond Earth and is located near the asteroid belt of the Milky Way galaxy.

The facility sports a state-of-the-art aquaponics system, where fish such as tilapia provide nutrients to the plants, and the plants clean the water. Vertically stacked farms and sensor-controlled environments are made efficient. Around 185 acres of cutting-edge agricultural systems, such as aquaponics and vertical farming, are used to meet the food and oxygen requirements of 15,000 people, thus making the habitat self-sufficient.

The facility incorporates foresight and ingenuity into its technological arsenal to remain impervious to future challenges, such as CRISPR-edited plants capable of tolerating radiation and low light. Moreover, fungal bioreactors consume waste and produce oxygen, and black soldier fly larvae consume organic matter and produce protein feed. Various preservation techniques like drying and vacuum packing are used, and AI is in charge of the inventory and makes consumption predictions, while all of this is supported by eco-friendly packaging.

Exhaltra is a combination of earth, agricultural, and technological elements that are interdependent, not only to maintain the health of the residents but also to ensure the sustainability of the habitat, thus serving as a model for a future off-earth civilisation and showcasing the potential of humankind to adapt in the vastness of space.

POTENTIAL TIMELINE:

Year(s)	Task Description
0–4 Years	Transport materials to Ceres orbit: Deliver construction cargo to the assembly site.
4–6 Years	Assemble habitat and activate life-support systems.
6–8 Years	Develop food and environment sectors: Start aquaponics and advanced growth systems.
8–10 Years	Run tests, tune systems, and begin partial crew stay.
10+ Years	Establish a self-sustaining, autonomous settlement.

2. Structural Design & Zoning

At its core, the design of Exhaltra pairs **flexible, compressible, inflatable sections** with **hard, carbon-fibre, and composite-material shells** tailored separately for the **asteroid surface** and **orbit**. These hybrid modules balance the challenges of **launch volume** and **protective strength**, enduring **micrometeoroid impacts**, **cosmic radiation**, and structural stresses from **station rotation** and environmental changes.

Artificial gravity is generated through **ring modules** or **petal-shaped expansion wings**, helping reduce the negative effects of low gravity on the human body. The **modular structure** allows for **phased assembly** and future growth, supporting increased population and more complex missions.

Exhaltra has residential quarters, research labs, recreation areas, and hybrid farming lands. **Advanced technology** keeps the **whole habitat clean** and **free from any kind of contamination**. **The apartments have climate, thermal, and noise isolation systems**, as well as **Earth like lighting and natural materials** to help the residents' mental health. Labs have sterile air and the most modern safety features for the handling of biological and chemical experiments. Farming units use **vertical farming, aeroponics, and aquaponics** with very accurate **light** and **moisture levels** to **maximize yield and eco friendliness**.

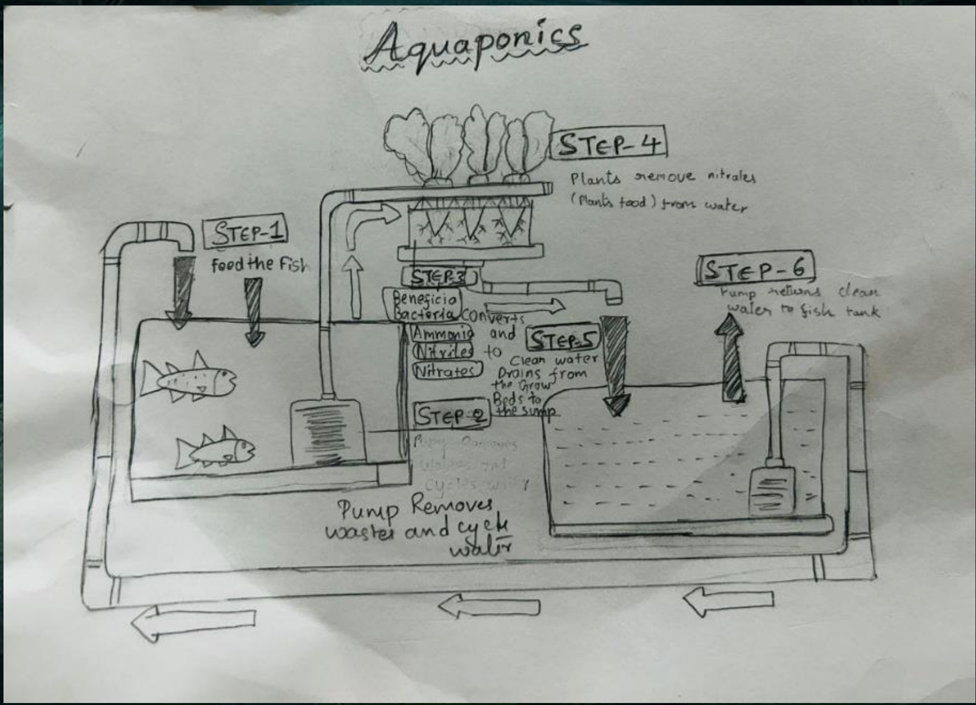
An **intelligent circulation system** is used to manage the air that **separates cleaned and contaminated zones**, thus **minimising biological cross-contamination** and at the same time allowing the movement to be smooth**. Recreational** and **exercise areas** are outfitted with **variable-gravity treadmills, advanced fitness equipment, and natural features** to enhance the health and morale of the crew.

3. Advanced Food Production: Aquaponics-Centred System

Exhaltra's farm utilizes a **closed-loop regenerative system** based on **aquaponics**. Technically, the system involved **fish farming** combined with **crop production without soil**. To say the least, the method **reuses water** from **fish ponds for irrigation** and vice versa. The focus is on the farming of **tilapias and catfishes** since these are **eco-adaptive** and have the **shortest developmental period**. **Bacteria for nitrification** are also added to the system to **get rid of the ammonia**. **Nitrates are produced** from this **conversion** and are **very helpful to plants**. **Plants** like **leafy greens, herbs, and root vegetables** make use of these elements thus they **purify the water** for the fish tanks.

Exhaltra's Agri modules are powered by **vertical farming racks** to **optimise space,** thereby the **total growing area is increased** several times over the traditional ones while the same footprint is kept. **An elaborate sensor network** keeps on checking **temperature, pH, dissolved oxygen, nutrient levels, and microbial activity**. Thanks to this **Integrated control system,** all factors **remain precisely balanced**, ensuring a **stable environment**, **efficient resource management** and consistently **high productivity**.

The **waste conversion unit** is a device that is fitted with **black soldier fly larvae** that are **used to consume the organic waste**. **The larvae**, when they are fed, become a **high protein food source** for **fish** and **poultry**, and thus **nutrient cycles are closed. This interconnected system**, which is especially **designed for use in space**, **lessens** the need for **supplies from Earth**, makes r**esource** use **more efficient,** and at the same time, **provides** the **crew** with the **necessary protein and micronutrients for their health**.

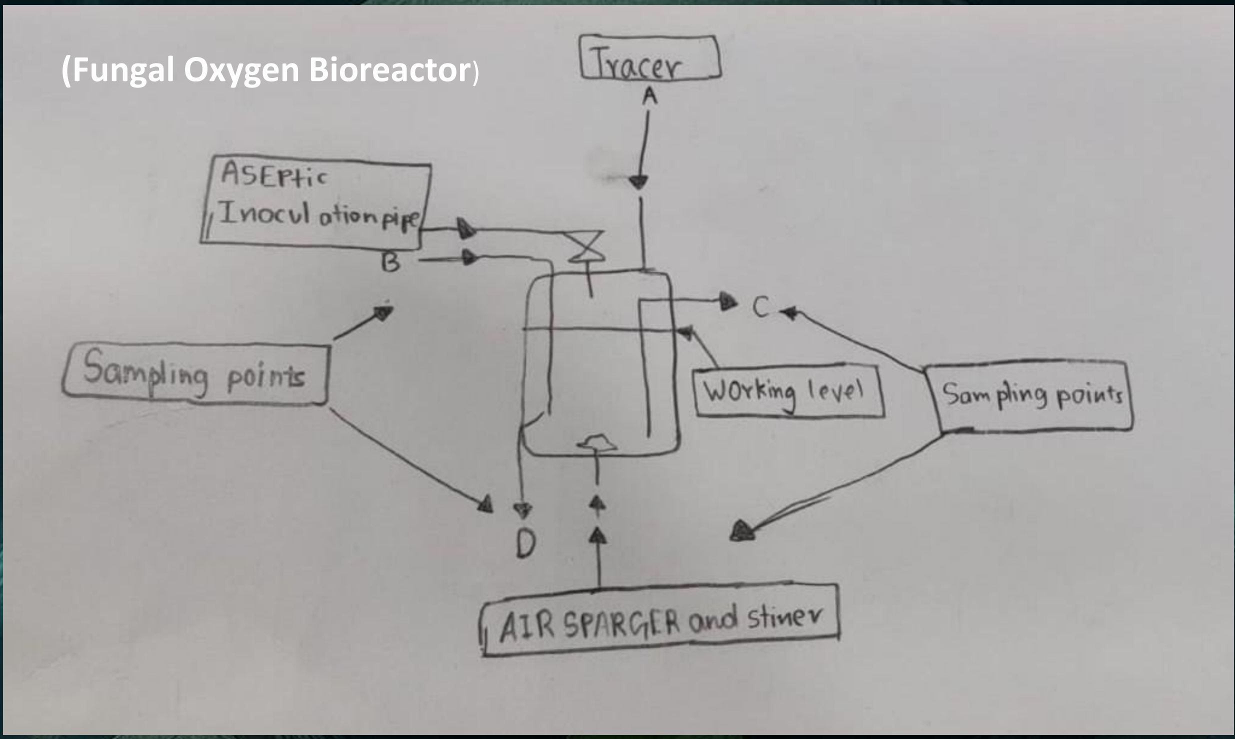


Steps included in the image.

- **Step 1**: Feed the fish.
- **Step 2**: Pump removes waste and cycles water.
- **Step 3**: Beneficial bacteria convert ammonia and nitrates to nitrates.
- **Step 4:** Plants remove nitrates (plant food) from water.
- **Step 5**: Drain clean water drains from the grow beds to the sump.
- **Step 6**: Pump returns clean water to fish tank.

4. Gene Technology and Fungal Oxygen Generation

Exhaltra habitat crops are made possible by **CRISPR-Cas9 gene-editing technology**, which allows the plants to be resistant to **ionising radiation, drought, and low light,** which are the **typical conditions in the asteroid belt**. **Genetic alterations** to specific genes to induce **dwarfism traits,** that **allow more compact crop packing** and **efficient nutrient cycling.**



Microbiomes, geneticallymodified and bred for **susceptibility to pathogens** (pathogens resistance) have been provided **nutrition through the exchange of nutrients in the rhizosphere**, which has been a **safe environment** for them and thus **supports** the **controlled growth conditions**. **Fungal oxygen bioreactors** filled with **genetically modified mycelial species** are there for **oxygen supplement** or **other gas exchange functions** in the **controlled environment.**

Advanced **Hyperspectral imaging** and **Raman spectroscopy** are the Techniques used on **Exhaltra** to obtain the most detailed data on the **physiological parameters of the plants**, their **stress levels**, and **nutrient content**, which, in the end, makes it possible to give the **precise and timely interventions** necessary to **optimise plant health**, **resource use efficiency**, and **productivity**.

5. Food Preservation and Supply Assurance

As the supply missions to Exhaltra are few and far between, food preservation has become a necessity not only **to keep and maintain** the **nutritional quality** but also to **ensure storage stability** for a **long time**. In order to satisfy these requirements, **various advanced methods** which **combine** both **traditional and innovative technologies** have been used to preserve nutrients, extend shelf life and reduce waste effectively.

These ways are necessary to bring about the said results:

- **Freeze-Drying**: In this case, the water in the food is removed by **sublimation**. Thus, the **vitamins and minerals** are kept, and the **nutritional value** along with the **texture remain** the **same**.
- **Vacuum Packaging**: The thing that makes this method different is that by removing the air from the package, **the process of oxidation** and **microbial growth** is **stopped**, thus **the shelf life of the product is extended.**

- **Fermentation**: Fermentation products **like kimchi, kombucha, and yoghurt**, are very rich in **probiotics**, which **help the digestive system and the immune system**, and at the same time, give **flavor diversity to the diet**.

- **Controlled Atmosphere Storage**: Compartments for storage fitted with **monitoring and control devices** regulate the amount **of oxygen (O_2) and carbon dioxide (CO_2).** In this way, the processes of **oxidation and spoilage are slowed.**

- **AI-Driven Food Inventory Systems**: These systems employ **sensors and predictive algorithms** to keep up with the food condition continuously and to **consumption timing** optimization thus **very little food waste** is generated.

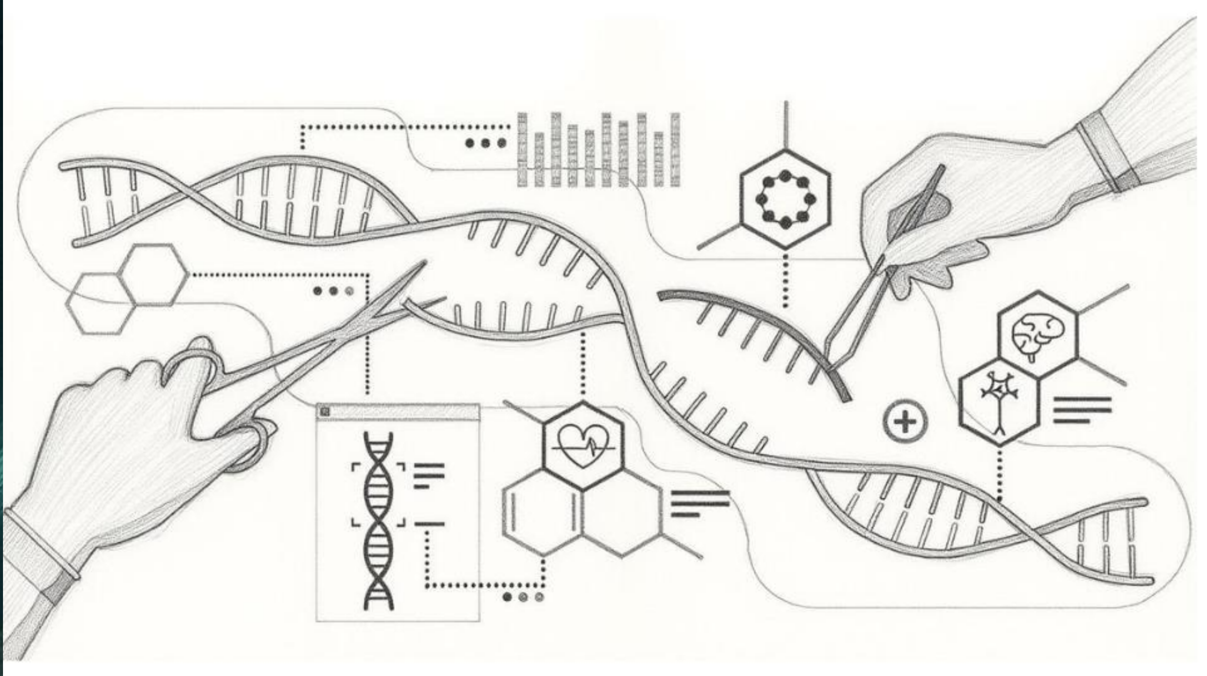
- **Sustainable Packaging Solutions**: The packaging, coming from **recyclable** or **edible materials**, is a supporter of the **habitat's closed-loop sustainability goals** thus there is **minimal environmental impact.**

By the use of these methods, **Exhaltra** is making sure that a **stable**, **nutritious**, and **environmentally** friendly **food supply** is available, which is capable of withstanding the infrequent **resupply missions**.

6. Genetic Resilience: CRISPR, Microbial Bioengineering, and Fungal Oxygen Generation

Exhaltra is using a series of highly advanced **CRISPR-Cas9 gene editing techniques** to have the genes of the crops altered in such a way that the modified plants can be cultivated in the region of the **belt of the asteroids**, which is an extreme environment for life. The **radiation of space**, **low gravity**, and a lack of **resources** are the main features of these environments. As a result, the plants have been genetically engineered to be more resistant to **radiation**, more tolerant to **drought**, and to exhibit traits typical of **dwarf plants**. For that reason, they may be grown at higher densities, and the **nutrients taken from the soil** can be utilised more efficiently by the plants.

We manage to do it is tha/ through the engineering of the **microbial communities** that live in the roots of the plants with **microbes that have been created specifically** for this purpose. This supports the plants to continue getting nutrients easily, defending themselves against enemy organisms, and stabilising the **rhizosphere**, a stage necessary for the development of plants in controlled environments. This sort of **bioengineering** is a guaranteed way to high agricultural output, even if an existential challenge should faced.



Besides, they are a necessary backup for the **regeneration of the atmosphere** through the absorption of the system's by-products. The **fungi** in question are those that do not need a lot of light to grow, and they convert **carbon dioxide into oxygen** while at the same time decomposing **organic waste**; thus, they are closing multiple **resource loops**. This system, a result of the research on fungi done by **NASA on the asteroid**, increases the resilience of the habitat and the possible **life support systems** are not limited only to **algae**.

7. Food Technology: Multimodal Preservation, Fermentation, and Edible Innovations

Exhaltra employs a robust, multifaceted food preservation strategy, taking into account the **vast distances** and **frequent resupply costs** in the **asteroid belt**. **Freeze-drying preserves nutrients**, **vacuum packaging prolongs freshness**, and **controlled atmosphere storage** reduces **spoiling** by **controlling CO_2** and **oxygen levels**.

Exhaltra's space diet becomes **more nutritious and healthier** with the addition of **live probiotics** through **fermenting food**s **like kimchi, yogurt, and kombucha**. **Probiotics** are essential in supporting **digestion, immunity, and mental health**, which are the three systems most affected by the **stress of spaceflight. Food supplies** are managed in **real-time** by an **AI-driven inventory and monitoring system**, which is full of **advanced sensors** and **predictive algorithms**, thereby **spoilage is effectively reduced, crew nutrition is enhanced, and menu variety is introduced to prevent monotony**.

Packaging revolution by means of **biodegradable, compostable materials, and edible coatings** very much **lowers waste**, thus moving **Exhaltra** further along its way towards **circular sustainability** in the **habitat ecosystem.**

8. Water Recovery: Systems, Milestones, and Redundancy

Exhaltra's water system is an excellent instance of a **closed-loop system** that **is eco-friendly** and has a **recovery efficiency** of over **98%,** which is **very important** because of **the long distance** to the **asteroid bel**t. The system consists of:

1. **Urine and greywater recycling**: These processes include distillation, filtration, and catalytic oxidation to make water suitable for drinking.

2. **Air humidity harvesting**: Uses the condensate from crew and plant transpiration to meet water requirements.

3. **Multi-layer purification**: Changes the water through ion exchange, reverse osmosis, and UV sterilisation to make it free from contaminants and pathogens.

4. **Biological brine treatment:** Microbes in reactors that eat salts and organics in the brine, thus lowering the waste volume and the risks that go with it.

An **automated purification adjustment** system pairs with **perpetual water quality monitoring** to ensure a safe and continuous water supply for **drinking**, **hygiene**, and **crop irrigation**.

9. Oxygen Production: Photosynthetic and Fungus-Driven Subsystems

The **main source** of **oxygen** on **Exhaltra** is a **synergistic system** of **photosynthetic microalgae (Chlorella vulgaris and Spirulina) cultures** and **genetically engineered fungal bioreactors**. **Algae cultures absorb CO_2 and release oxygen** along with **protein-rich biomass for nutrition. Fungal bioreactors** take in **atmospheric CO_2** and **organic waste**, release **oxygen**, and thus provide **system redundancy** that is very useful during **algal shutdowns periods** or when there are **adverse environmental conditions.**

Real-time atmospheric sensors are always on, and they detect **respiratory gases** to levels that allow the **bioreactors to be dynamically modulated**; thus, they are in **harmony with the metabolism** and the **activity cycles of** the **crew**. Using **local in situ CO_2 from asteroid materials makes oxygen regeneration more efficient and reliable.**

10. Nutrition: Dynamic Menus, Monitoring, and Countermeasures

Exhaltra's diet plan is based on the idea of **avoiding and lessening the central body changes** resulting from **small gravity in the space capsule for a long time**. These changes are **atrophy of muscles**, **loss of bone density**, **weakening of the immune system**, **and metabolic disorders**.

The **nutrition system** of the habitat provides **very balanced diets** that **average a total daily intake** of **2,500 to 3,000 kcal** with the **macronutrients being roughly 50-55% carbohydrates, 25-30% fats**, and **15-20% proteins**. The primary **proteins sources** are **predominantly coming from the fish in** the

aquaponics system, **legumes that are genetically modified**, and **protein made from insect farming (black soldier fly larvae).**

Crew members receive **vitamin D**, **calcium**, **omega-3 fatty acids**, and **antioxidants** to compensate for deficiencies caused by limited space and to maintain their vigor. **Prebiotic fibers** and **fermented foods** support gut **microbiota health**, **improving digestion** and **psychological resilience**.

Personalization comes from **wearable biosensors** that constantly monitor **metabolic rate**, **hydration**, and **nutrient levels**. The real-time data is used by **AI-driven adaptive menu planning** to optimize **nutrient balance**, **lessen dietary boredom**, and **meet individual physiological** needs **under different workloads** and **mission phases**. **The meal plan** for **space** is:

Meal	Typical Components	Key Nutritional Features
Breakfast	Fermented yoghurt with probiotics, genetically engineered legume porridge, and omega-3-enriched fruit compote	High protein and probiotics to support gut health and metabolism
Lunch	Aquaponics fish fillet (tilapia/catfish), leafy green salad with prebiotic fibres, vacuum-packed root vegetables	Balanced protein, fibre, antioxidants, and sustained energy from complex carbs
Dinner	Insect protein patties (black soldier fly larvae), fermented kimchi or kombucha, steamed herbs and greens	High protein, fermented food for digestion and immunity
Snacks	Freeze-dried fruit pieces, nuts, and probiotic-rich beverages	Nutrient-dense, maintaining energy and microbiome health
Supplements	Vitamin D, calcium, antioxidants	Countermeasure for space-induced nutrient deficiencies

11. Sustainability: Biological, Physicochemical, and Socio-Technical Waste Management

It is through the achievement of **closed-loop sustainability** that Exhaltra can be viable for a long time, as the remoteness of the asteroid belt makes it necessary. **Oxygen** is also released as a result of the biological processing of organic waste through **photo-digesters** and the use of specially developed **bacteria** that convert biomatter into **nutrient-rich soil amendments**, thus helping **atmospheric regeneration**.

The **non-edible parts of plants** serve as **insect food** that, in turn, provide **high-protein feedstock**, thus closing **nutrient cycling loops. Non-recyclable impurities** are **compressed and stored** for future **repurposing**, such as **radiation shielding** or **structural materials**. **Sewage** is made **extremely clean**, and **mineral recovery operations** take reusable **nutrients** from the **wastewater**.

The core component of **Exhaltra 's socio-technical infrastructure** is **strict waste segregation** measures which are supported by **crew training and digital monitoring**. These integrated measures contribute to **maximizing resource recovery**, **reducing the risk of contamination**, and **minimizing the habitat footprint**.

12. Energy Systems: Solar Arrays, Batteries, Fusion, and Grid Resilience

Energy on Exhaltra mainly comes from **super-efficient triple-junction photovoltaic solar arrays**, which are specially designed to capture as much solar energy as possible even in the changing light of the asteroid belt. To that end, **high-capacity lithium-ion** and cutting-edge **solid-state batteries** are installed to smooth out the fluctuations in energy use.

Experimental micro-fusion reactors are on hand to provide power during the ship's **eclipses** and **solar storms**. The shipboard **smart grid**, managed by an **AI**, can **forecast use**, actively directs energy to the most vital systems, and also keep **storage balanced**.

Besides that, there are **thermoelectric converters** and **solar concentrators** to increase the usable energy, and the presence of **redundancies** and **fault-tolerant features** ensures that the ship will not suffer power failures and that the **life-support system**, **scientific work**, and the habitat's **thermal regulation** will continue even when it is dark for some time or the conditions are rugged.

13. Human Factors: Ergonomics, Culture, Group Psychology, and Habitability

Exhaltra, **fully aware of the singular microgravity issues** in the **asteroid belt habitats**, has included in its features **ergonomic designs that put musculoskeletal health** first through **specially designed exercise modules** and a **workspace that can be adjusted**. The **lighting**, which can be **adjusted** to the **needs of the person** and **the circadian rhythm**, and the **multisensory soundscapes help** the **mental health of the crew** by **providing** a **day-night rhythm** and **nature** that are **like those on Earth**.

The installation of privacy modules, the **availability of virtual reality cabins**, and **the existence of communal social areas** help the **psychological well-being** of the inhabitants by giving them a choice of **isolation** or **interaction with others**. The crew members from different countries receive through the behavioural health programme a thorough **training which emphasises the cultural adaptability**, **the skill in resolving conflicts**, and **the use of communication** as a means to **encourage** the **unity of a group** in a **situation** of confinement **and isolation**.

14. Safety: Fire, Radiation, Contamination, and Emergency Preparedness

The **habitat rigorously deals with the increased fire risks** that are typical **in oxygen-enriched atmospheres** through the use of **real-time fire detection systems**, **nontoxic suppressant sprays**, and **compartmentalised safety zones**.

Radiation shielding is performed by **thick regolith covers**, **high-density polyethene materials**, and **advanced magnetic fields** that **lower the dose of galactic cosmic rays**. **Contamination control** features are **multi-stage airlock systems**, **sterilisation chambers**, and **isolation wards** designed for **medical contingencies**.

The **emergency preparedness ensemble** is made complete by the presence of **autonomous firefighting drones, layered evacuation routes** allowing **rapid crew egress**, and **trauma response facilities** capable of handling a **wide range of health crises**.

15. Operations, Scalability, and Global Expansion

Exhaltra's food system portrays **a futuristic concept** of keeping the **astronauts healthy** while being **ecologically responsible** on **long missions**. The **live probiotics—basically bacteria—through fermented foods** like **yoghurt**, **kimchi**, and **kombucha** are in the **diet**, which is an **active way** to **support digestion, immune system**, and **mental toughness**. These are very important for the **prevention of physiological and psychological problems** that **space travel entails**.

Food logistics on the **Exhaltra** are **simplified by an AI-driven inventory** and **monitoring system. This tech is sensor-packed** and **applies predictive algorithms** to **freshness**, **storage conditions**, and even to ensuring that **no food is going to spoil**. So, the **crew members** have **access** to **regular nutrition**, **improved food safety**, and a **diverse menu** that is able to provide them with the means to **combat** the **dietary monotony typical of long missions**.

One of the **most significant innovations** in this **system** is the **employment of sustainable packaging solutions**. With the use of **biodegradable**, **compostable materials and edible coatings**, **Exhaltra** is **cutting dow**n on **packaging waste** to a great extent and is **promoting circular resource management** in the **habitat ecosystem** of the **space station**. This **strategy**, in turn, **not only lowers** the **environmental impact** but also is in **agreement with Exhaltra's goal of attaining complete-cycle sustainability in space living.**

16. Artificial Gravity System

Rotational artificial gravity is the most viable method to simulate Earth's gravity in the Exhaltra habitat. The Exhaltra rotating habitat turns about a central axis with a radius of 1,000 meters, thus generating a centrifugal force to simulate Earth's gravity of $9.81\ m/s^2$. The law of centripetal acceleration is $g=\omega^2 r$. With that number, the habitat is able to create artificial gravity by turning at an angular velocity ω of about 0.099 radians per second, resulting in a tangential velocity of approximately 99 meters per second. Therefore, the gravitational effect is continuous and stable as the force is rotating once every 63.5 seconds.

The rotational formula is:

$$g=\omega^2 r$$

Where:

g is artificial gravity (9.81 m/s^2),

ω is angular velocity (rad/s),

R is the rotational radius (1,000 m).

As a matter of fact, linear acceleration, i.e., the uniform acceleration of the entire habitat at 9.81 m/s^2, would also produce gravity accurately. However, such a method requires propulsion to be carried out continuously, hence it is not feasible as a permanent solution. Accordingly, the use of rotational artificial gravity is the most energy-saving and environmentally friendly way to guarantee the crew's health in long-term space habitation.

This rotation gravity system keeps the musculoskeletal system, the cardiovascular system, and the normal physiological processes that are vital for human health in a prolonged space settlement in good condition. By doing so, physical and psychological resilience are made possible for the inhabitants of Exhaltra, which is essential for their survival.

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