From DNA to the Stars: Biological Research in the Space Age

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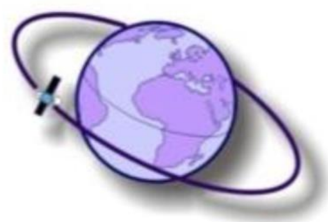
Key space environment factors for sustaining life

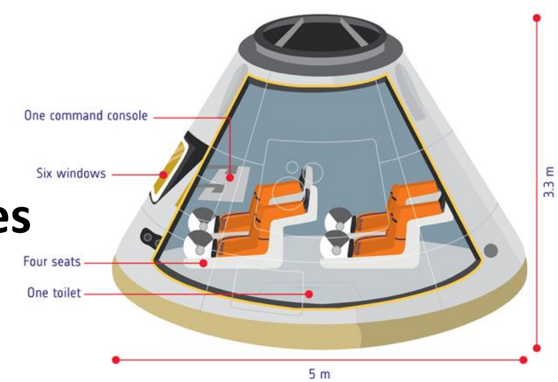
Hypergravity
Magnetic field changes
Vibration

Microgravity



Increased concentration of CO_2
Circadian rhythm disorders

Cosmic Radiation

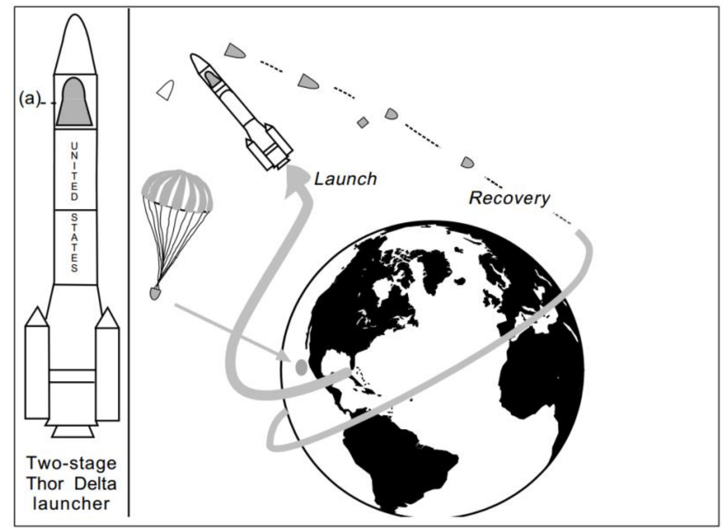


Vacuum and extreme temperatures

Isolation and closed-loop systems

The beginning of biological research in Space

- **1940s-1960s**: First experiments before man flew into space:
- Shows the possibility of survival of a variety of organisms in low Earth orbit (LEO) (**up to 500 km**) and when passing through **Van Allen's inner belt** (Drosophila, bacteria, plants, turtles, mice, dogs, chimpanzees) as preparation for manned space missions



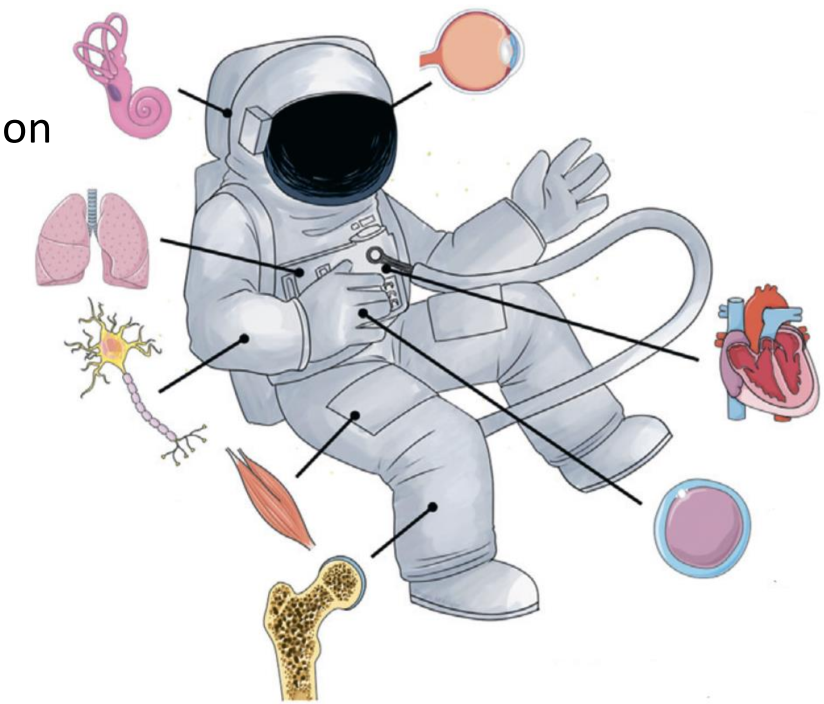
1961-2025: Manned missions and orbital stations. The Impact of Spaceflight on the Human Body

600+ humans have traveled to space since 1961

300+ dedicated experiments conducted on human health in microgravity

Major impacts discovered:

- Fast muscle & **bone loss** (up to 20% decline on long missions)
- Cardiovascular changes (fluid shifts, "puffy face" syndrome)
- Radiation-induced **DNA damage** (150-300 mSv/year on ISS)
- Neurovestibular disruption (space motion sickness)
- Temporary vision impairment (SANS)
- **Weakened immunity**



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Musculoskeletal System - Bone Loss (Spaceflight Osteoporosis)

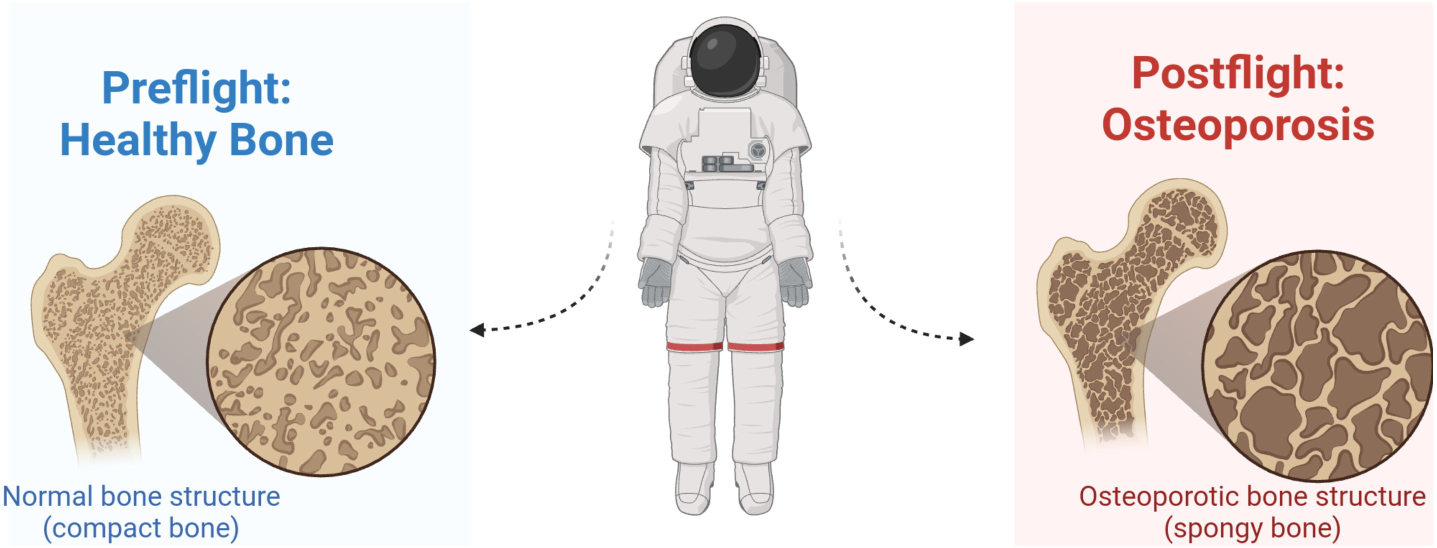
In microgravity, bones no longer bear weight, leading to **accelerated bone resorption**.

Loss rate: Up to **1–2% of bone mass per month** (compared to 1–2% per year in elderly people on Earth). Most affected areas: **spine, pelvis, and legs**.

Risks: Increased fracture risk, prolonged recovery.

Countermeasures:

Daily exercise and novel drug development to prevent bone loss.



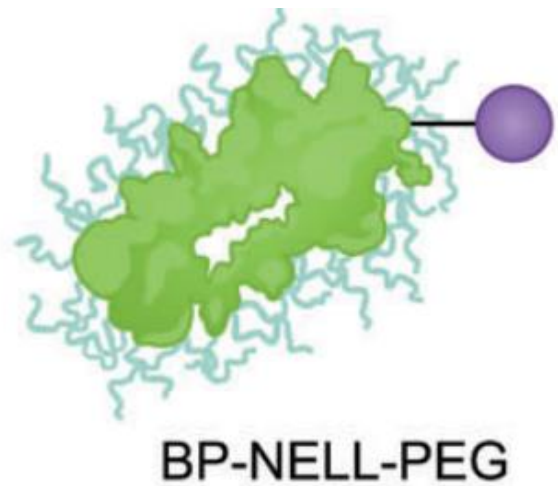
1961-2025: Manned missions and orbital stations. The Impact of Spaceflight on the Human Body

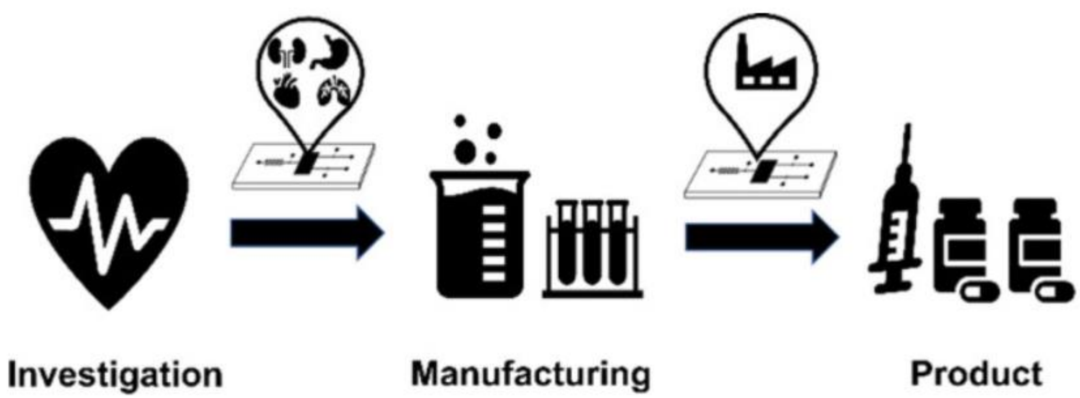
Drug development:

Breakthrough Candidate:

BP-NELL-PEG (engineered bone-growth protein)

- During the 9-week space mission, mice received injections of the test BP-NELL-PEG every 14 days
- **Result**: Significantly increased bone formation in spaceflight (mice)
- Upcoming Phase I human trials

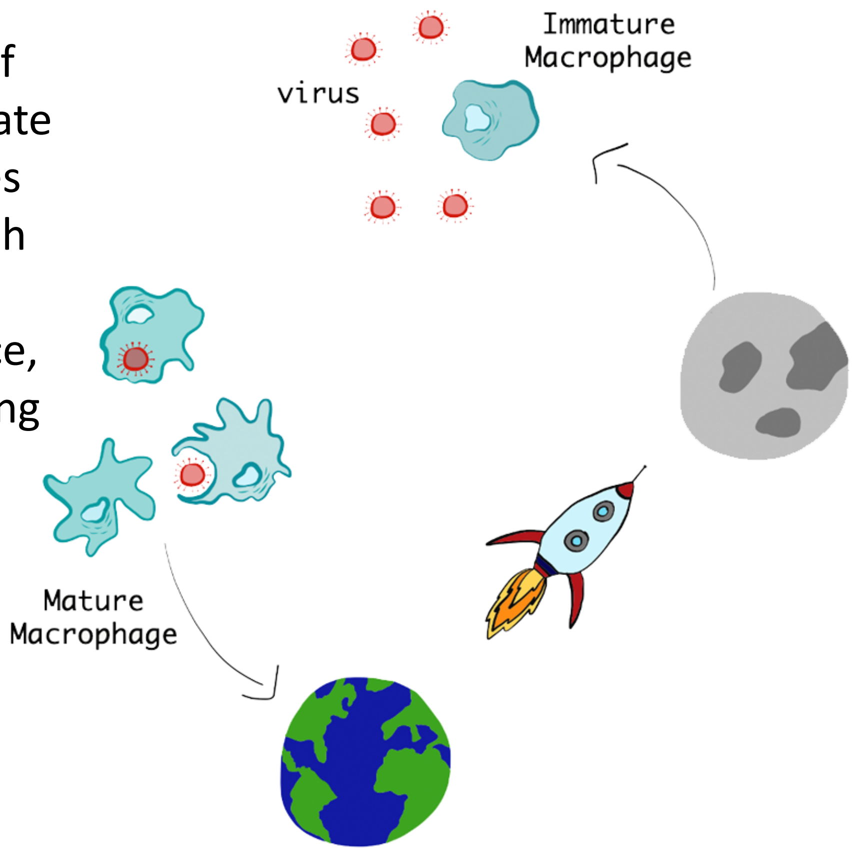




1961-2025: Manned missions and orbital stations. The Impact of Spaceflight on the Human Body

Immune System: Weakened immunity (similar to aging or chronic stress):

- Under the normal physiologic conditions of Earth, macrophages mature and differentiate to eradicate invading pathogens like viruses and bacteria. One way that they accomplish this eradication is via phagocytosis, or engulfment, of pathogenic threats. In Space, this maturation process is stunted, impairing the ability of macrophages to fight viruses and other pathogens.



Causes:

- Microgravity + radiation + psychological stress.

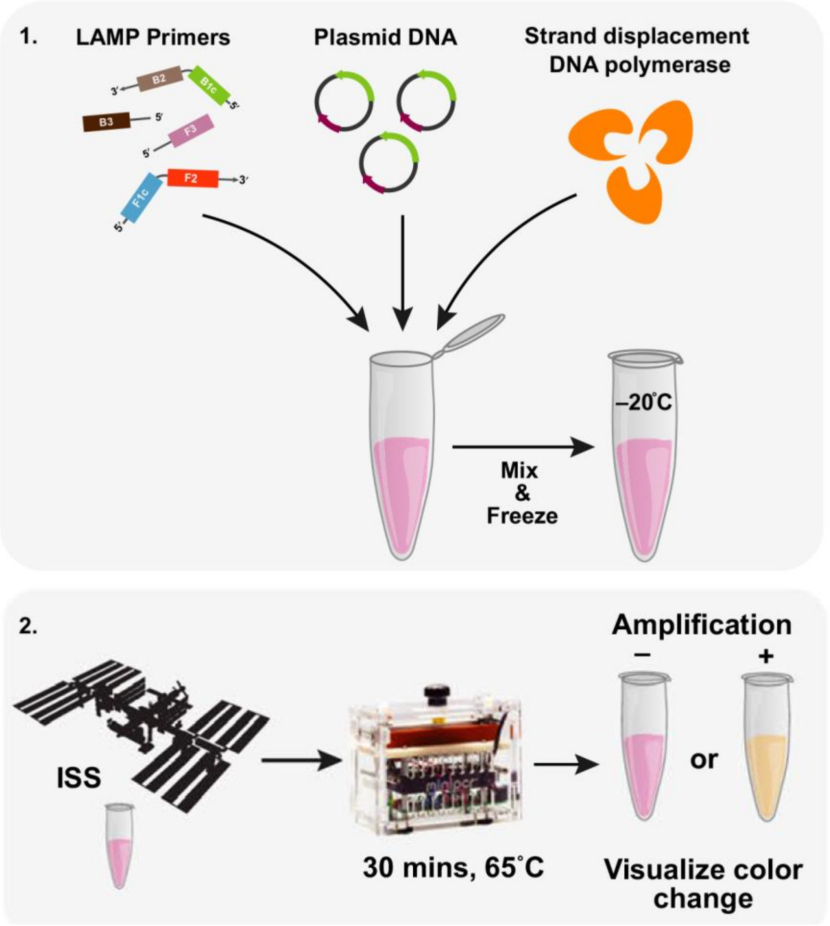
Countermeasures:

- Strict medical monitoring, antiviral medications.

1961-2025: Manned missions and orbital stations. The Impact of Spaceflight on the Human Body

Rapid Pathogen Detection in Space Using LAMP Technology (Loop-Mediated Isothermal Amplification)

- **Pre-Prepared Kits**: Frozen tubes containing all necessary reagents are sent to the space station.
- **Sample Addition**: A purified sample (e.g., from human, air, water, or surfaces) is added to the tube.
- **Heating:** The tube is heated to 65°C for 30 minutes.
- **Color Change = Result**



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Rapid pathogen detection in space using LAMP technology

The science behind It:

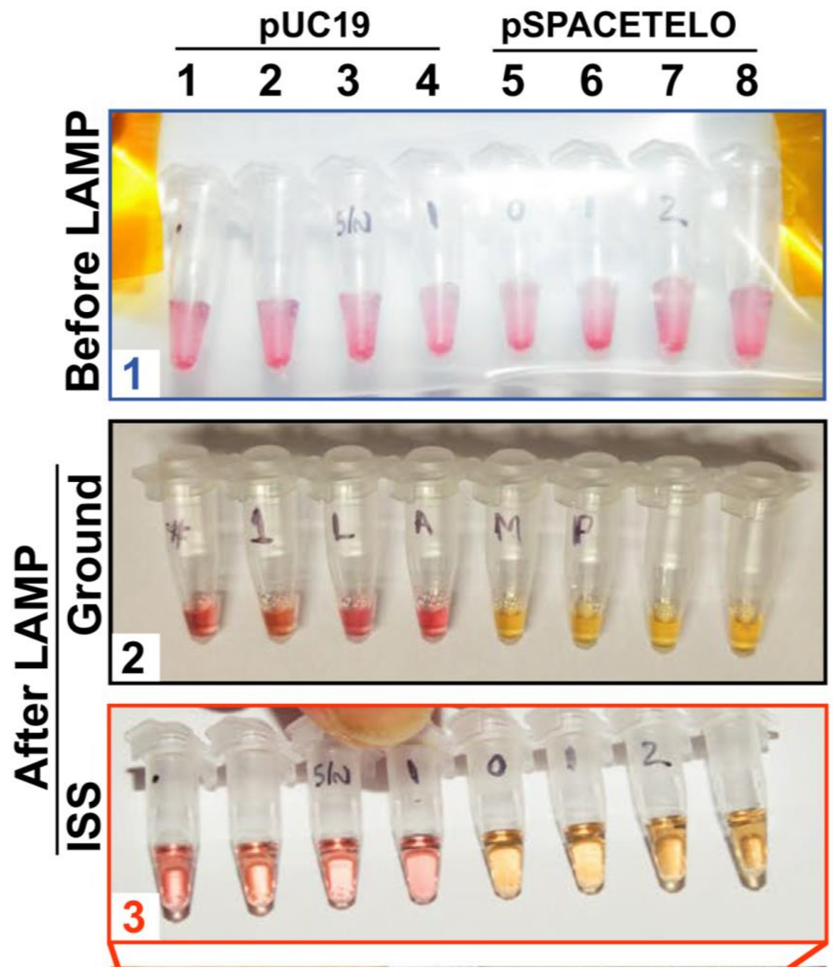
- LAMP mimics natural bacterial DNA replication, rapidly copying pathogen DNA.
- As DNA multiplies, pH changes, triggering the color shift.

Tested Successfully:

- **System works with Earth-added DNA** samples (proof-of-concept confirmed on the ISS).

Remaining Challenges:

- Adapt sample purification for microgravity.
- Develop pathogen-specific reagents (e.g., for space-relevant bacteria/viruses).



1961-2025: Manned missions and orbital stations. The Impact of Spaceflight on the Human Body

DNA damage + Natural Killer cells dysfunction:

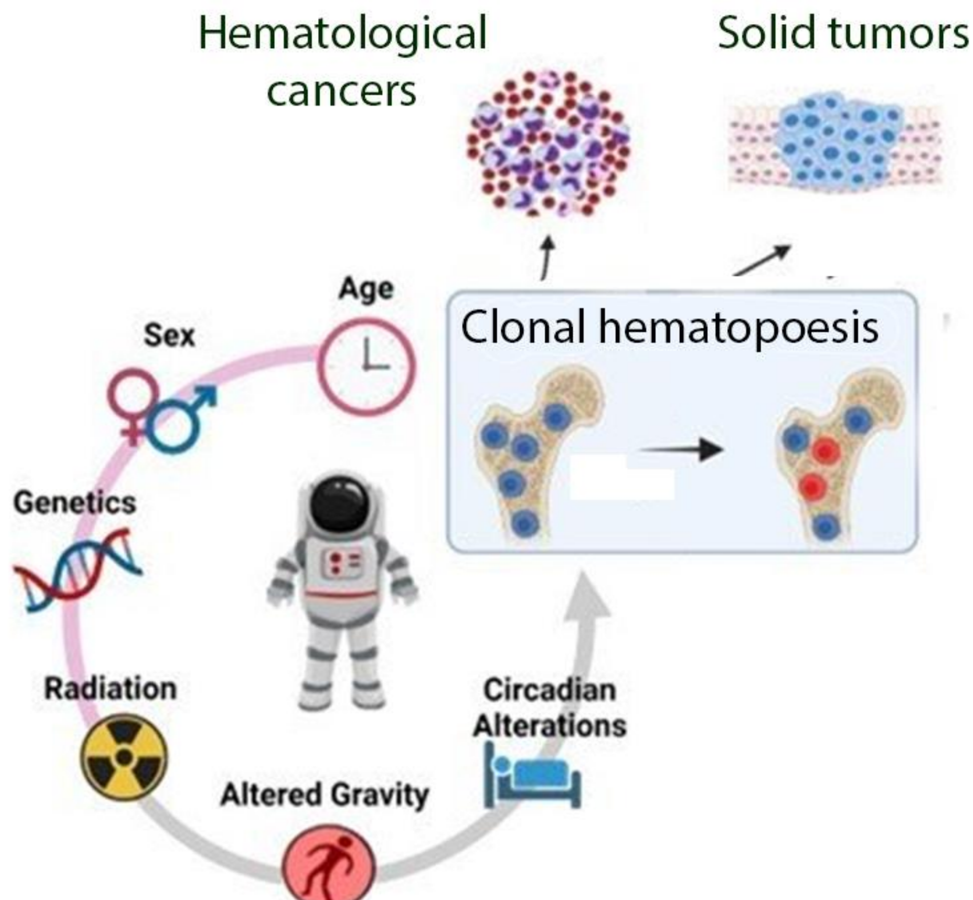
- On the ISS, radiation exposure is 100–200 times higher than on Earth

Risks:

- Increased mutation and cancer risk

Protection Strategies:

- Shielding in crew modules.
- Solar flare monitoring.
- Research into radioprotective drugs (antioxidants, gene therapy).



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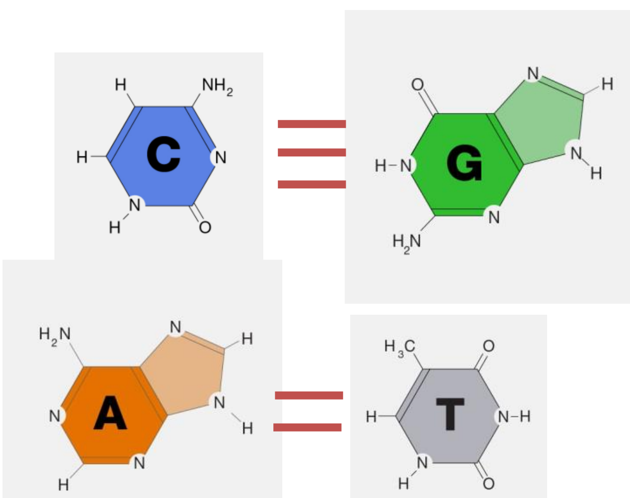
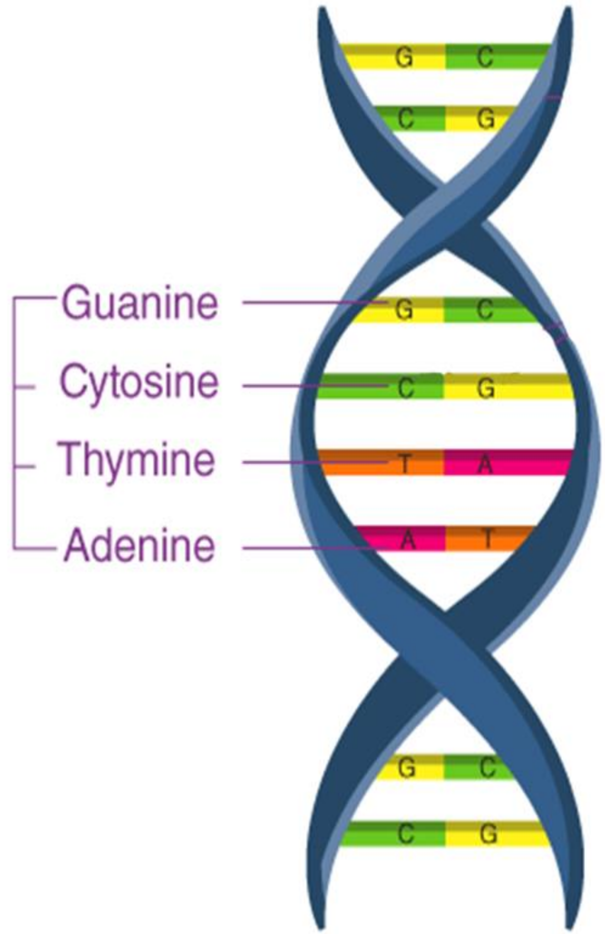
DNA damage and mutations mechanism:

- DNA is a **linear biopolymer** with two twisted strands (double helix).
- Each strand consists of **4 nucleotide monomers** (A, T, C, G).
- The **sequence of monomers** encodes genetic information.





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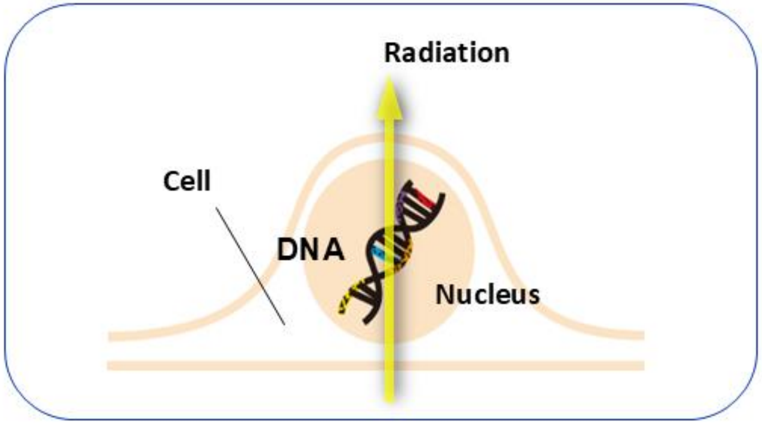
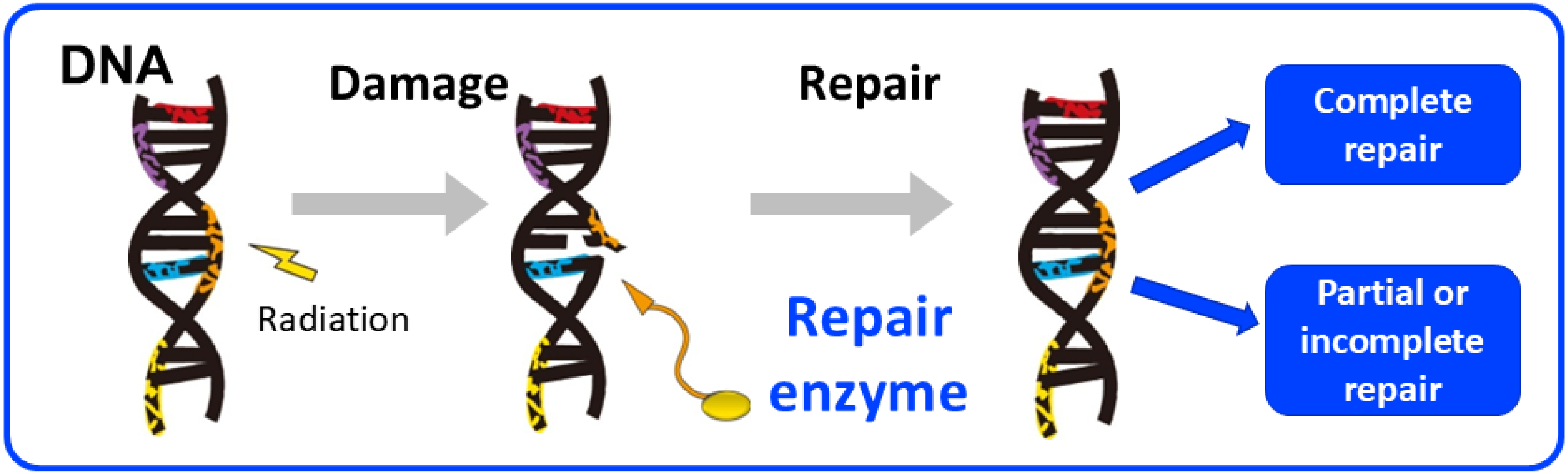
DNA damage and mutations mechanism:

- Radiation causes **DNA strand breaks**.
- Cellular repair systems fix **some but not all damage**.
- **Higher radiation doses = more breaks = more unrepaired damage**.





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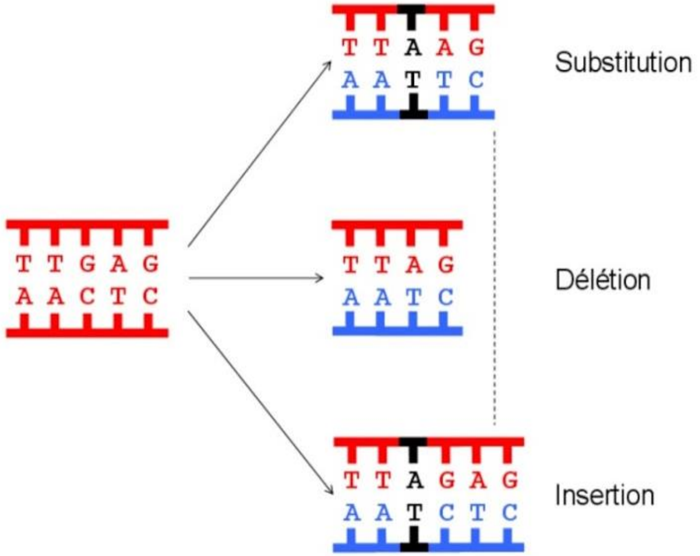
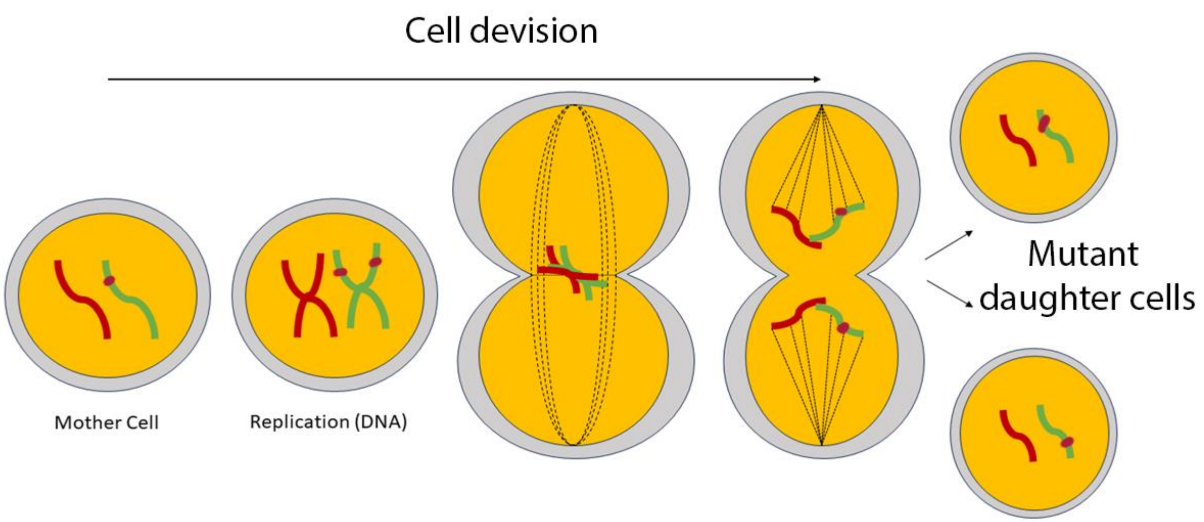
DNA damage and mutations mechanism:

- During cell division, damaged DNA is **copied with errors**.
- **Mutations** occur if breaks are unrepaired (wrong nucleotides inserted).
- Mutations propagate to **all descendant cells**.





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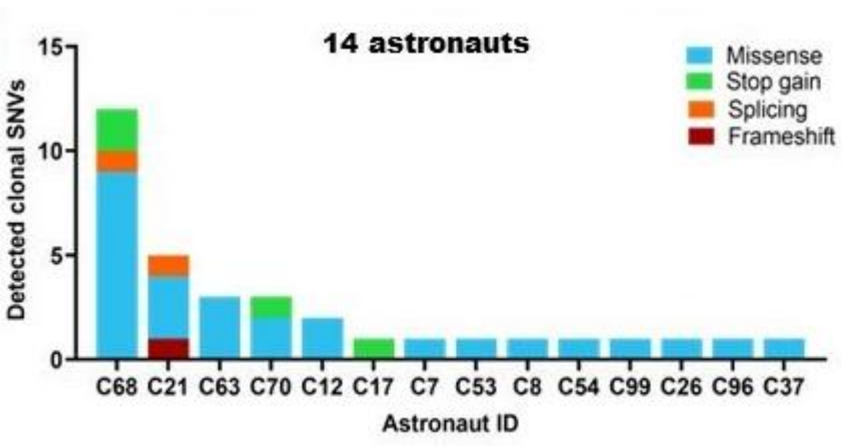
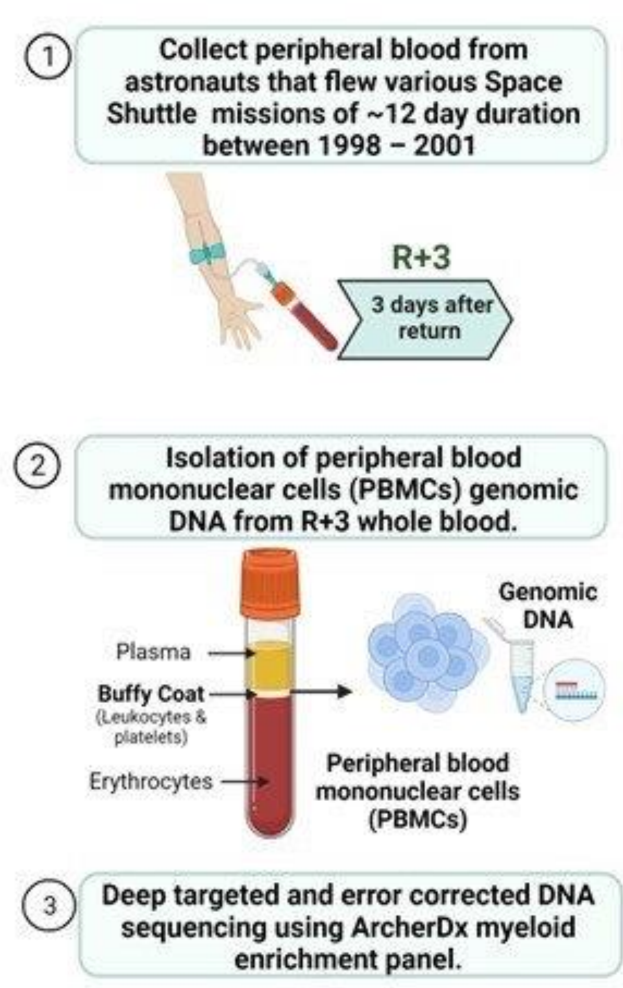
DNA damage and mutations outcome:

Germ cells (sperm/egg): Mutations can be **inherited by offspring**.

Somatic cells:

- Neutral mutations: No effect.
- Harmful mutations: Cancer risk (e.g., tumor formation).
- 34 mutation events found in 14 astronauts blood samples:





1961-2025: Manned missions and orbital stations. Radiation resistance drug development

Tardigrades (Water bears): Nature’s Radiation Shields

Extremophile superheroes:

- Survive **1,000× human-lethal radiation** (5,000 Gy)

Cryptobiosis:

- Replace 97% body water with **trehalose "glass"**
- Pause metabolism for **decades** in "tun" state

Thermal superpowers:

- **−272°C to 150°C** (near absolute zero to boiling)

Space-tested:

- First animals to survive **open space** (2007 ESA)
- 68% revived after **10 days in orbit**

1961-2025: Manned missions and orbital stations. Radiation resistance drug development

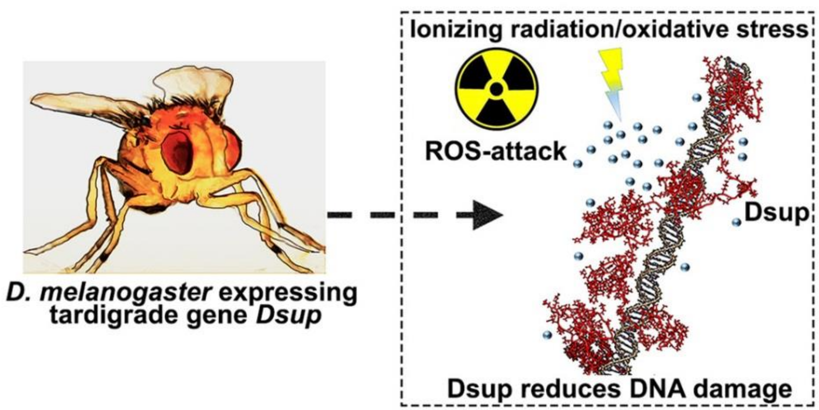
Tardigrades radio resistance secret – Damage suppressor protein (Dsup)

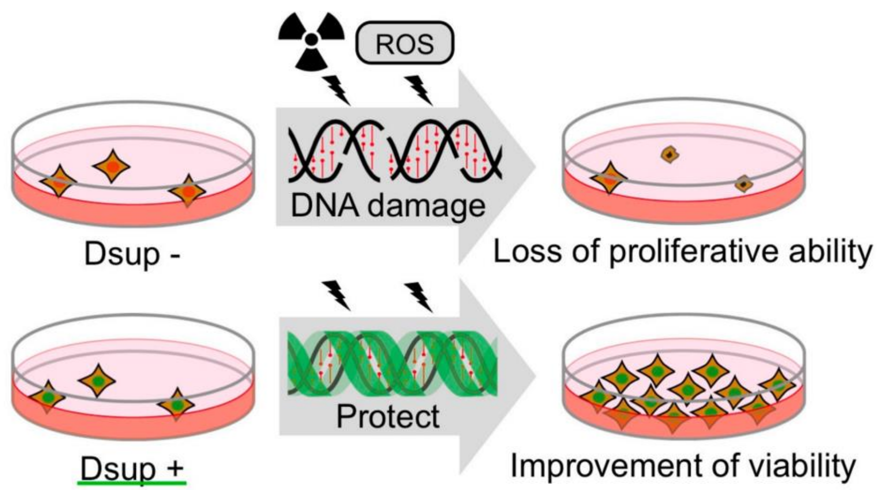
Unique protein found only in tardigrades (*Ramazzottius varieornatus* strain). It acts like a "force field" for DNA, protecting it from ionizing radiation

- **Dsup binds to DNA** forming a **protective cloud** around DNA strands
- Blocks radiation-induced breaks by **~40%** in human cells
- Dsup integration into the **Fruit fly** genome enhance its radiation resistance

Side effects:

- reduce the level of locomotor activity
- down-regulate RNA expression





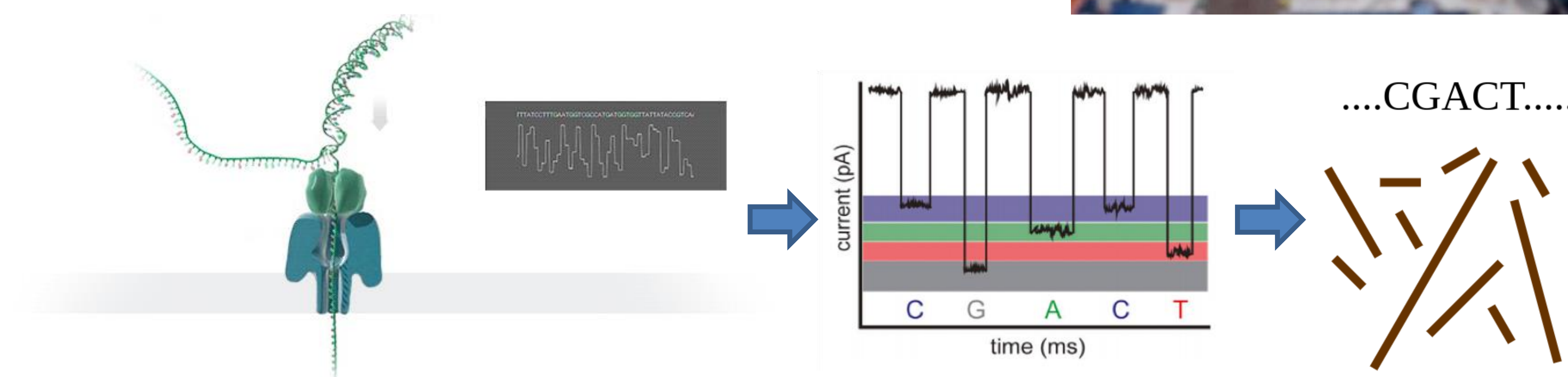
1961-2025: Manned missions and orbital stations. Nanopore Sequencing

Portable, USB-sized sequencer (Oxford Nanopore)

- Works in real time with DNA sample
- Adapted for working onboard of ISS

Detection:

- Bacteria/viruses genomes (pathogen identification)
- Radiation mutations (genome sequencing)



1961-2025: Manned missions and orbital stations. CRISPR Cas9 for gene therapy

“Molecular scissors" that can:

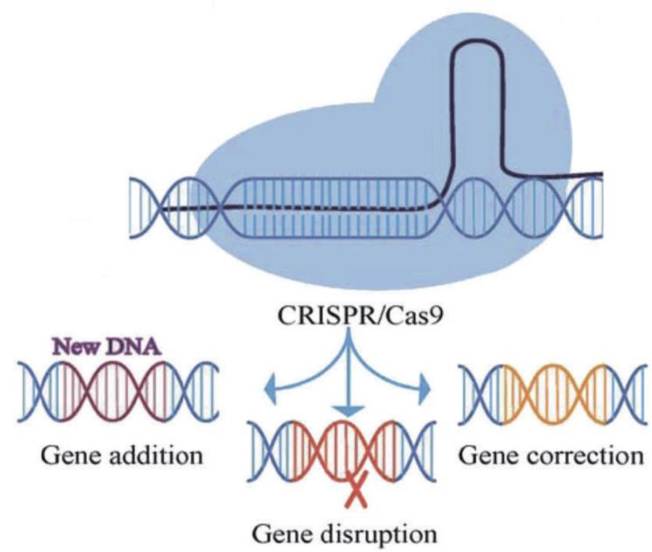
1. Cut out a defective DNA section
2. Replace it with a healthy sequence

Current Progress:

- Works in human cell cultures (lab-grown cells)
- Tested successfully in microgravity on the ISS
- Approved for human therapies: Blood disorders (e.g., sickle cell anemia)

Key Challenges:

- Sometimes gives off-target effects"
- Ethics: Debate over editing human embryos/heritable DNA
- Targeting: Requires a pre-designed "address tag" (guide RNA) to find the exact gene



A self-sustaining, closed life-supporting ecosystem development

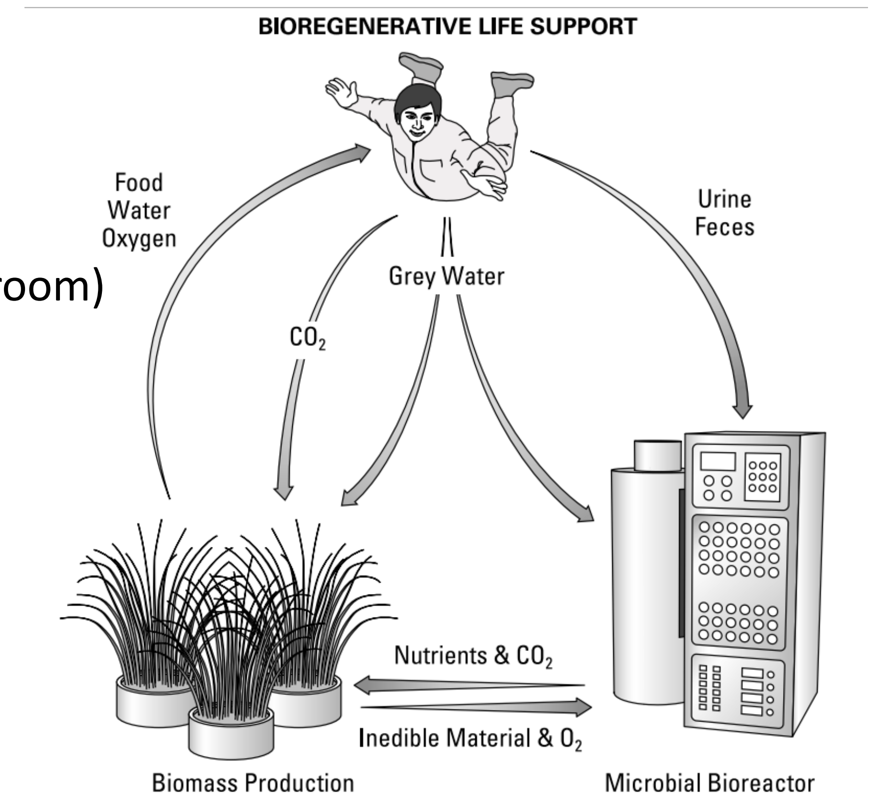
- **There are two ways to build life-support systems for space:**

"Full Ecosystem" approach

- Many different plants/animals/microbes
- Can adapt to problems naturally
- Best for: Mars/Moon bases (needs more room)

"Simple & Compact" approach

- Uses just a few key plants/bacteria
- Relies on machines for extra support
- Best for: spaceships (saves space/weight)



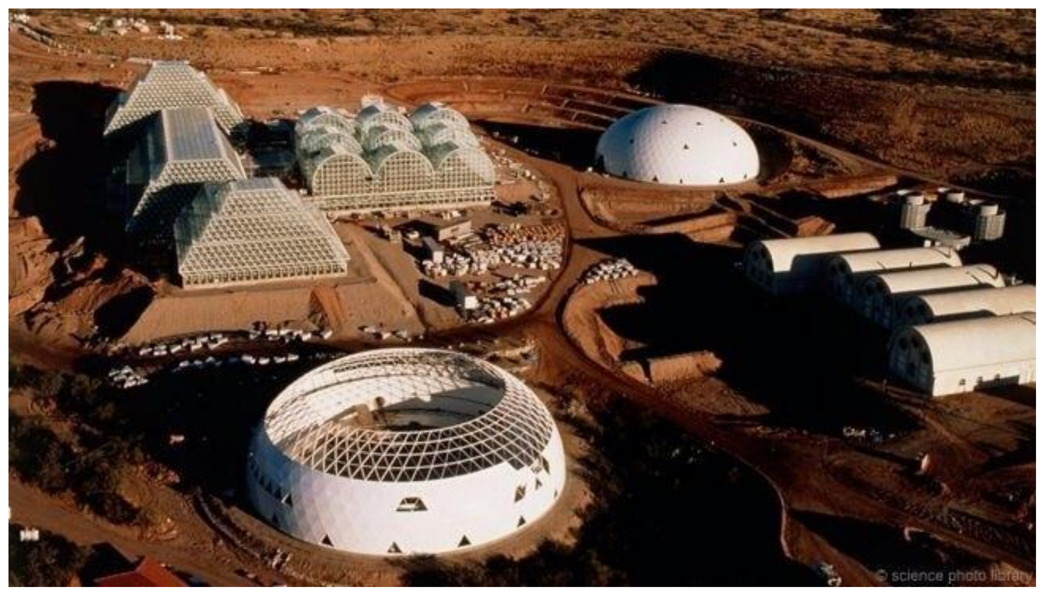
A self-sustaining, closed life-supporting ecosystem development

Biosphere-2 project

- Built in the 1990s in Arizona by Space Biosphere Ventures and billionaire Edward Bass
- Cost: $200 million
- Goal: Create a sealed, self-sustaining ecosystem to test if humans could live in closed environments (like on Mars or the Moon)

Ecosystems Inside:

- Rainforest
- Desert 🏜️
- Ocean (mini)
- Mangrove swamp
- Farmland



A self-sustaining, closed life-supporting ecosystem development

Biosphere-2 project

Key Stats:

- 3,000+ species (plants, animals, fungi, bacteria)
- 5-meter-deep soil
- Leak rate: <10% air loss per year
- Energy: Sunlight + electricity

A self-sustaining, closed life-supporting ecosystem development

Biosphere-2 project

The 2-Year Experiment (1991–1993)

- 8 people lived inside, growing 83% of their food

Surprises & Problems:

- Oxygen levels dropped due to explosive bacterial multiplication from 21% to 14% (like living at 4km altitude) → caused fatigue
- Crew lost weight, used emergency supplies
- Species died out (bees, vertebrates) → cockroaches & ants thrived
- Most stable ecosystem: Rainforest
- Least stable: Coral reef in the mini-ocean

A self-sustaining, closed life-supporting ecosystem development

Biosphere-2 project lessons Learned

Pros:

- Proved humans can survive in closed systems for years
- Showed ecosystems can adapt (but unpredictably)

Challenges for Space:

- Need better oxygen/food balance
- Must control microbes & pests
- Requires more reliable farming

Today

- Now owned by the University of Arizona
- Open for tours – a real-life "spaceship on Earth"

A self-sustaining, closed life-supporting ecosystem development

BIOS-3 – A Closed Ecosystem Experiment

Who Created It?

Two Soviet scientists: Sergei Korolev and Leonid Kirensky.

What Was It?

A sealed underground lab 14*9 meters where people lived for 6 months (1972–1973) to test if humans could survive in a self-sustaining environment**.**

A self-sustaining, closed life-supporting ecosystem development

BIOS-3 – A Closed Ecosystem Experiment

How Did It Work?

- The lab had four sections: one for living and three for growing plants.
- They grew dwarf wheat, vegetables (like carrots, potatoes, cucumbers), and algae (chlorella) under artificial light.
- The system recycled almost all air (oxygen & CO_2) and **95%** of water.
- Only **20%** of food came from plants—the rest was pre-packaged dried meals.

A self-sustaining, closed life-supporting ecosystem development

Later Experiment (1976–1977):

Lasted 4 months with 3 people.

Used special machines:

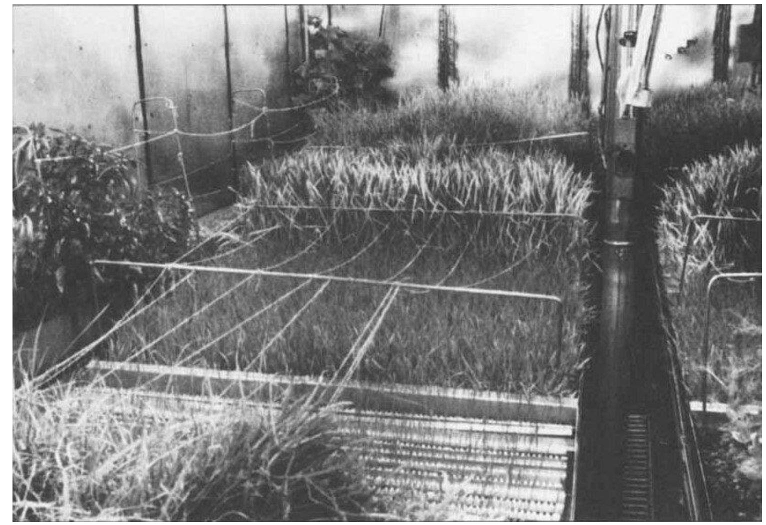
A furnace to burn plant waste.

A filter to clean the air and keep plants healthy.

This time, over half (52%) of their food came from plants they grew.

Problems Left Unsolved:

- How to close system up to 100%
- How to fully recycle dead plants back into the system.
- How to reuse human secreted salt.



A self-sustaining, closed life-supporting ecosystem development

"Yuegong-1" (Lunar Palace 1) – A Self-Sustaining Ecosystem Experiment (2018):

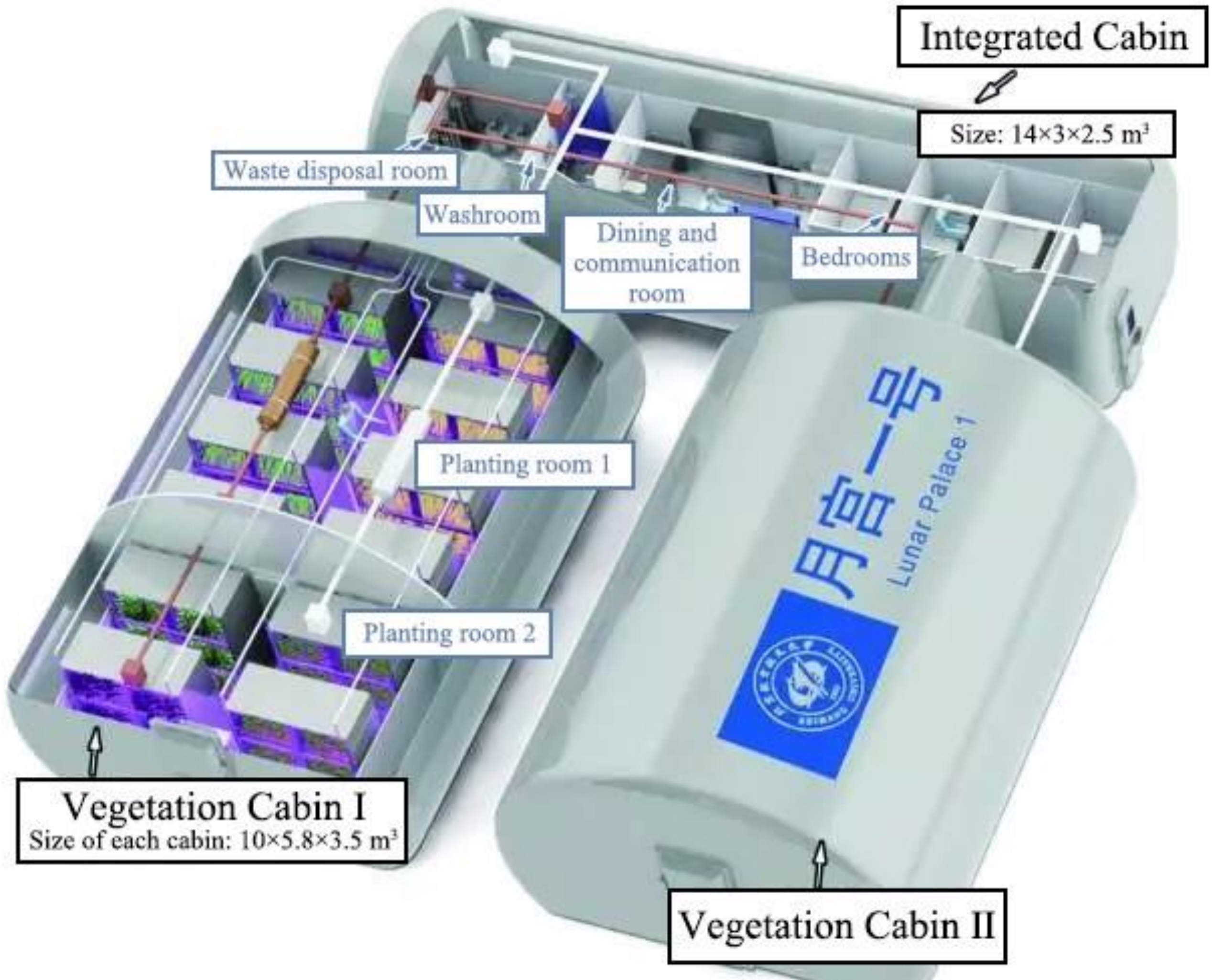
Key Features

A closed-loop life-support system where plants, animals, microbes, and humans worked together.

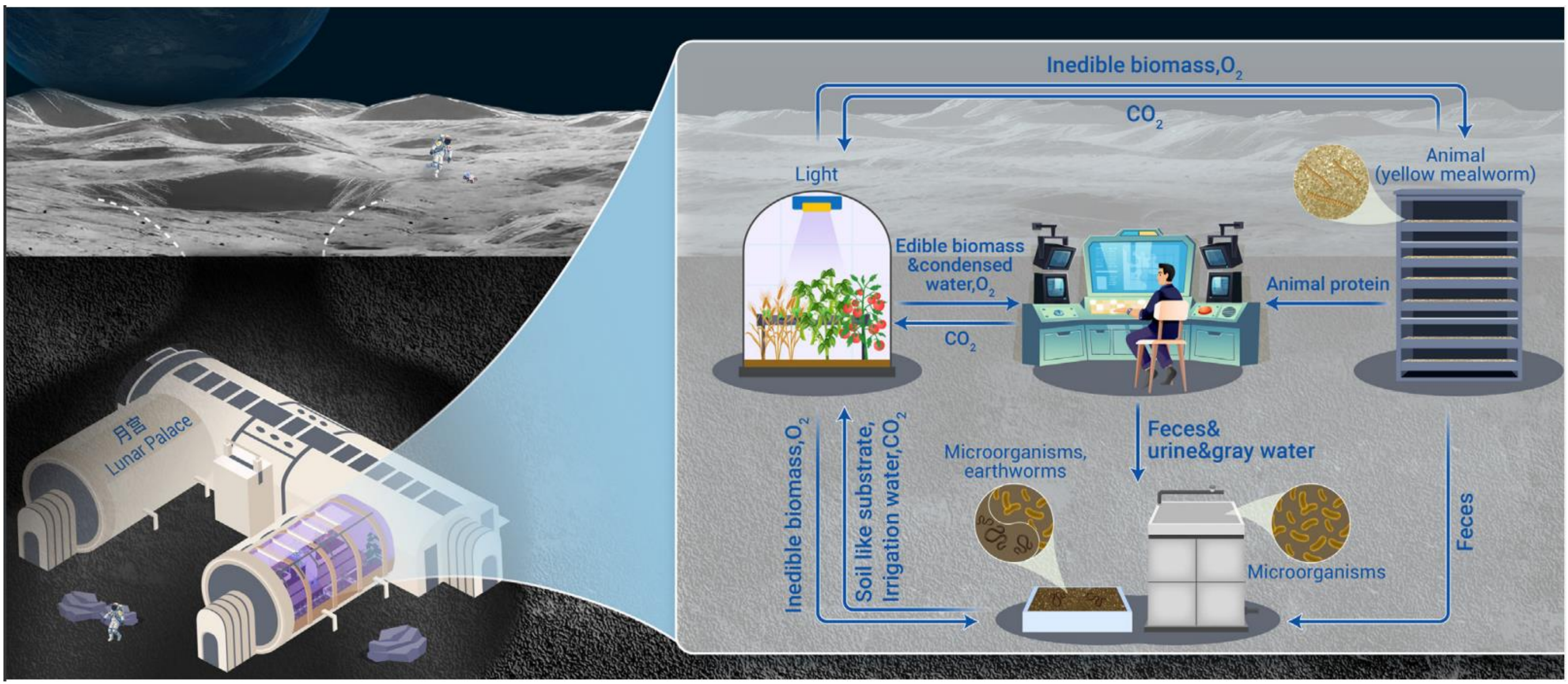
Food chain:

- Plants (wheat, soybeans, peanuts, chufa, corn, 15 types of vegetables, strawberries).
- Mealworms (fed on inedible plant parts, then eaten as a protein source).
- Some food (like cooking oil and meat) was supplied from outside, while waste and samples were sent out for analysis.

A self-sustaining, closed life-supporting ecosystem development



A self-sustaining, closed life-supporting ecosystem development



A self-sustaining, closed life-supporting ecosystem development

"Yuegong-1" (Lunar Palace 1) – A Self-Sustaining Ecosystem Experiment (2018):

How It Worked

- LED lighting (red spectrum) helped plants grow efficiently.
- Plants absorbed CO_2, produced oxygen, and helped recycle waste.
- Water was purified and reused.
- The crew could adjust conditions in each section.
- The First Experiment (105 Days, 3 Crew Members)

A self-sustaining, closed life-supporting ecosystem development

"Yuegong-1" (Lunar Palace 1) – A Self-Sustaining Ecosystem Experiment (2018):

Results:

- Fully closed for oxygen & water.
- 55% self-sufficient in food.
- 97% overall system closure.
- One crew member admitted struggling mentally but pushed through.

A self-sustaining, closed life-supporting ecosystem development

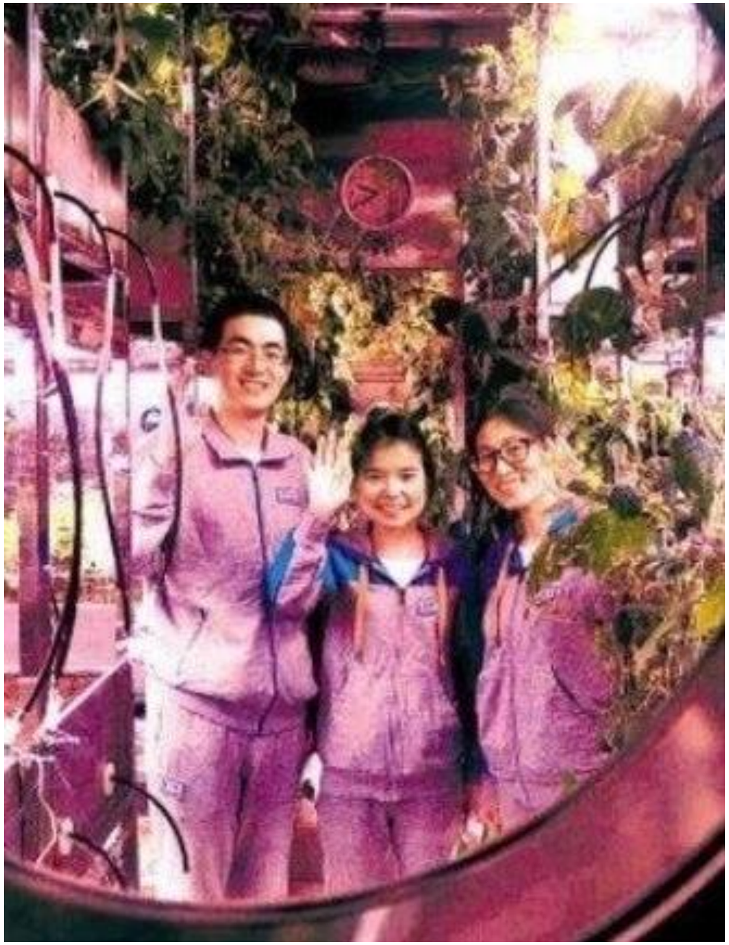
"Yuegong-1" (Lunar Palace 1) – A Self-Sustaining Ecosystem Experiment (2018):

The Second Experiment (370 Days)

Achievements:

- 99% air & water recycling (best result ever for closed ecosystems).
- 80% self-sufficient in food
- No health or mental issues despite long isolation.
- Simulation predicts the system could run for 52 years

This system will be used as prototype for Lunar station. In plans for 2030s.



A self-sustaining, closed life-supporting ecosystem development

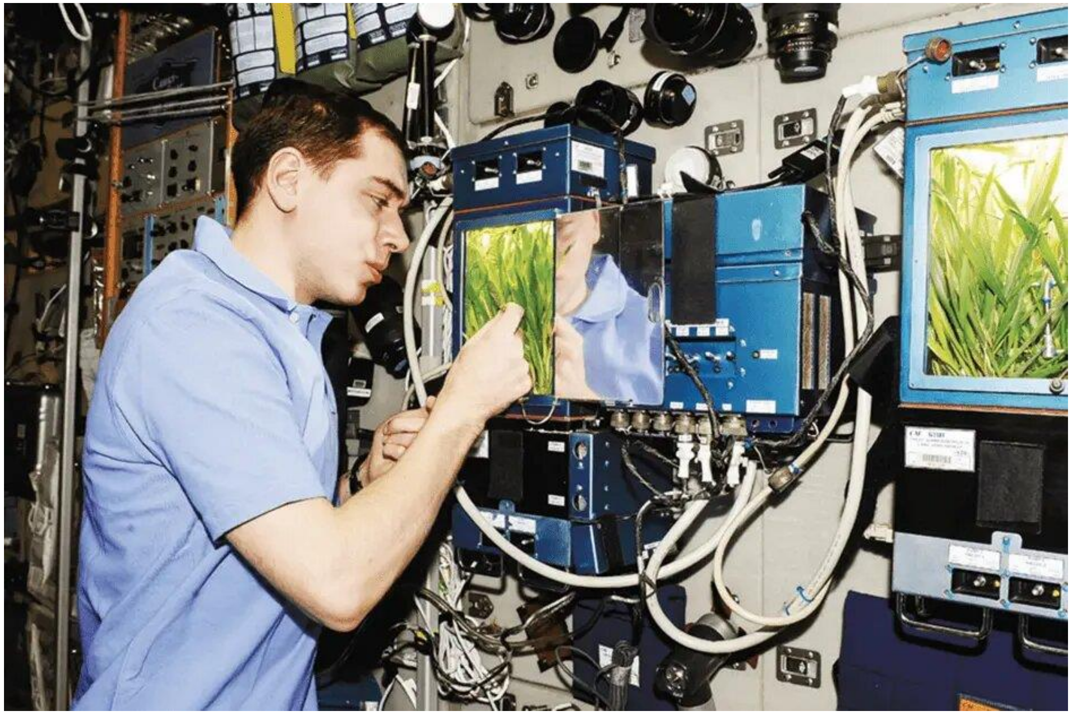
Plants that have been successfully grown and yielded crops on the

MIR station,

International Space Station,

China's Tiangong space station:

- **Wheat,**
- **Rice,**
- **Chili peppers**



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Future is coming