National Aeronautics and Space Administration

Design and Develop Science Missions

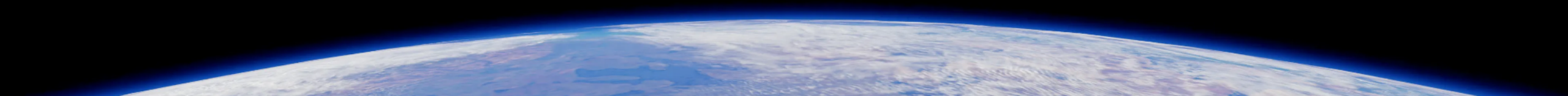
March 26, 2025

Access to Space for All Systems Engineering Webinar Series

Julie Levri
Flight Systems Engineer

Useful References

1. NASA System Engineering Handbook, NASA SP-2016-6105 (Rev 2)
   https://www.nasa.gov/reference/systems-engineering-handbook/
   Concept of Operations Outline, Appendix S
   https://www.nasa.gov/reference/appendix-s-concept-of-operations-annotated-outline/
2. NASA Systems Engineering Processes and Requirements, NPR 7123.1 (version D)
   https://nodis3.gsfc.nasa.gov/displayDir.cfm?Internal_ID=N_PR_7123_001D_&page_name=main
3. NASA Space Flight Program and Project Management Requirements, NPR 7120.5 (version F)
   https://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=7120&s=5E
4. NASA Research and Technology Program and Project Management Requirements, NPR 7120.8 (version A)
   https://nodis3.gsfc.nasa.gov/displayDir.cfm?Internal_ID=N_PR_7120_008A_&page_name=main
5. Risk Classification for NASA Payloads, NPR 8705.4 (version B)
   https://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=8705&s=4B
6. NASA Science Mission Directorate https://science.nasa.gov/learn/
7. System Engineering Curriculum Intro, 20210021839, https://ntrs.nasa.gov/citations/20210021839

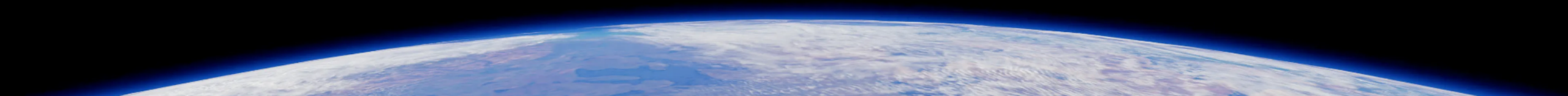


Webinar Overview:

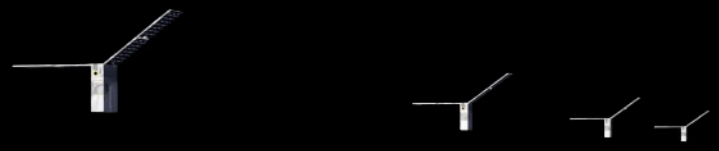
This webinar will conclude by providing an overview to design a concept mission applying various processes and tools described over the course of this series. This overview includes:

- What is defined as a science mission?
- What segments make up a science mission?
- What steps and processes are taken to design and develop a science mission?
- What are examples of a science mission design?

Purpose:
To provide attendees with information and knowledge of how to design and develop science missions.



What is defined as a science mission?



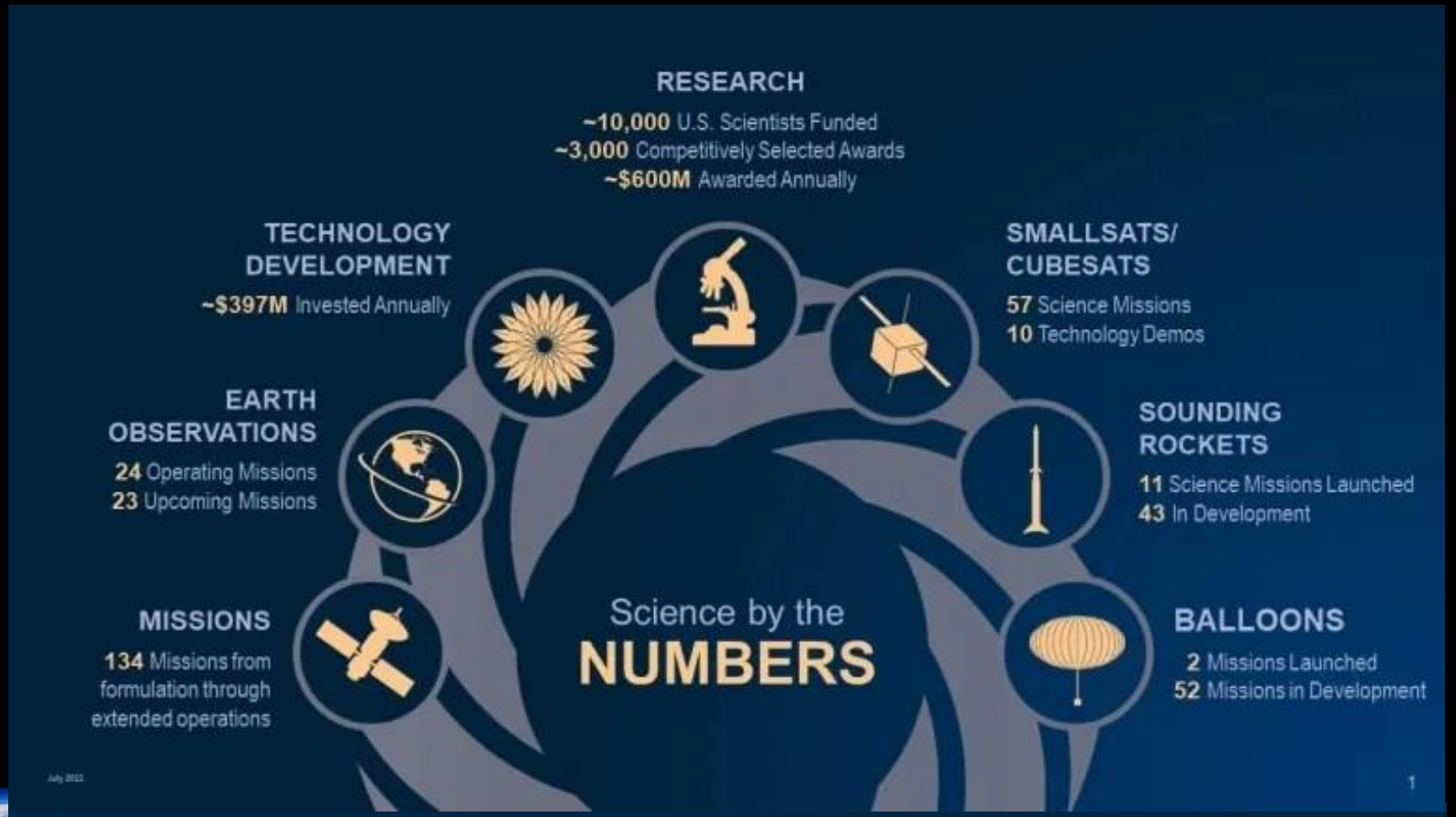
What is defined as a science mission?

For NASA, a science mission, managed by the Science Mission Directorate (SMD), is defined as a spaceflight mission primarily focused on scientific research and exploration, encompassing disciplines such as:

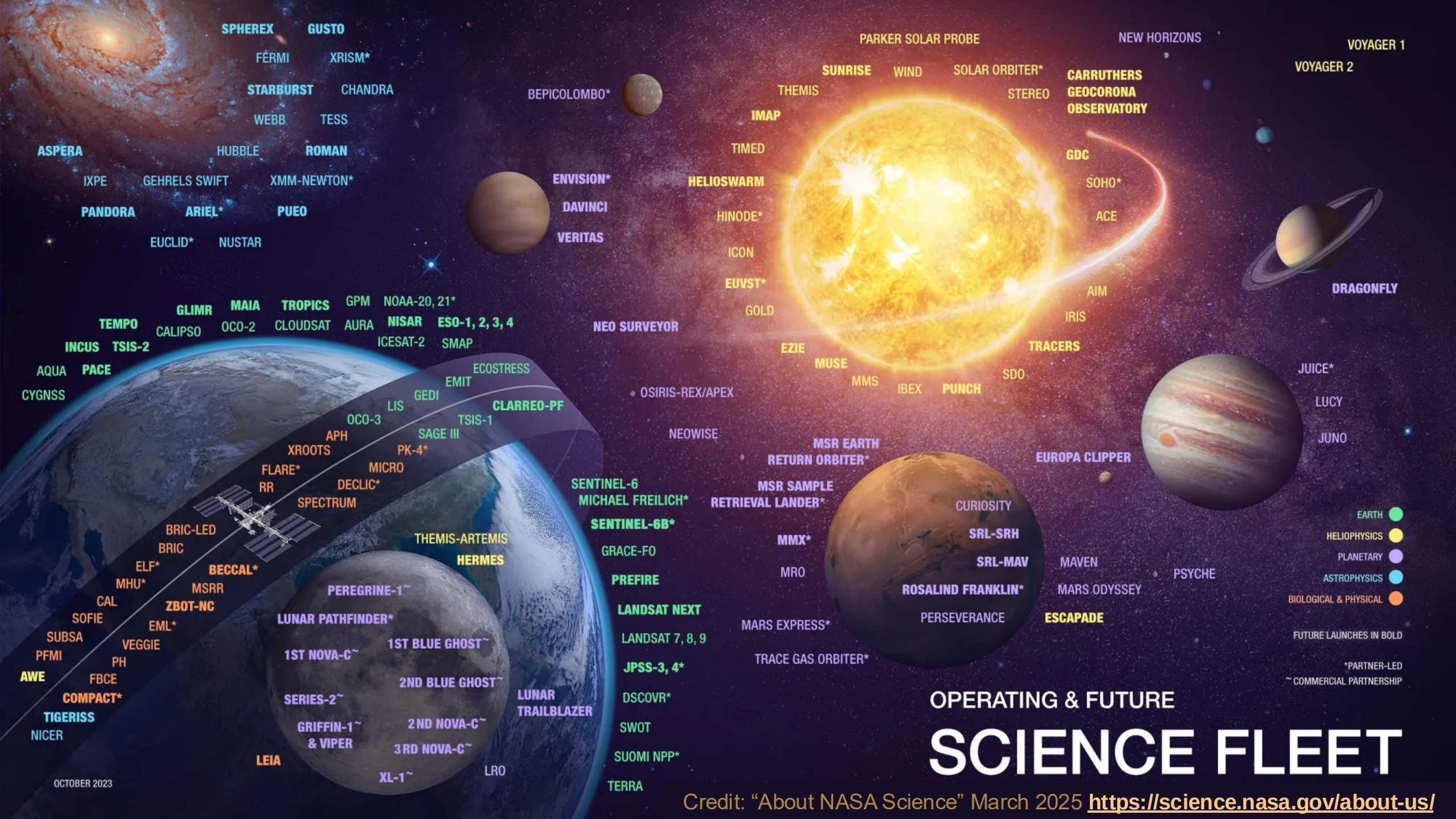
- Earth science
- Heliophysics
- Planetary science
- Astrophysics

with the goal of advancing scientific understanding and potentially benefiting humanity.

Science missions are usually driven by NASA Science Mission Directorate strategic plans, whereas the exploration missions may be driven by a Presidential directive.

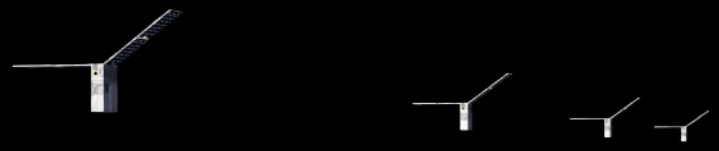


Credit: “About NASA Science” March 2025 https://science.nasa.gov/about-us/



Credit: “About NASA Science” March 2025 https://science.nasa.gov/about-us/

What segments make up a science mission?

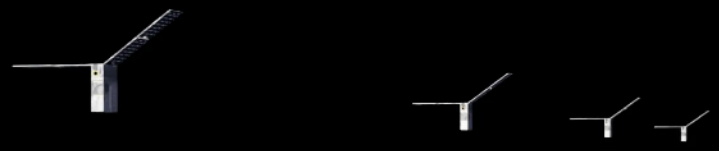


What segments make up a science mission?

A NASA science mission can be broken down into several segments:

- Launch segment: Launch vehicle and related services used to get the spacecraft into space.
- Space segment: Spacecraft and various components like orbiters, landers, rovers, and instruments used to collect data.
- Ground segment: Ground stations and mission control centers that communicate with the spacecraft, receive data, and manage the mission.
- User segment: Scientists and the public who will use the data collected by the mission for research and education.

What steps and processes are taken to design and develop a science mission?



Big Picture Process to Design & Develop a Space Mission

Example Research Mission – BioNutrients

What is BioNutrients? https://www.nasa.gov/general/what-is-bionutrients/

- Foods & supplements stored long-term, like in human missions to Mars, experience nutrient degradation.
- Can genetically-modified yeast that are degradation-resistant in spore form, be used to generate nutrients as they grow?

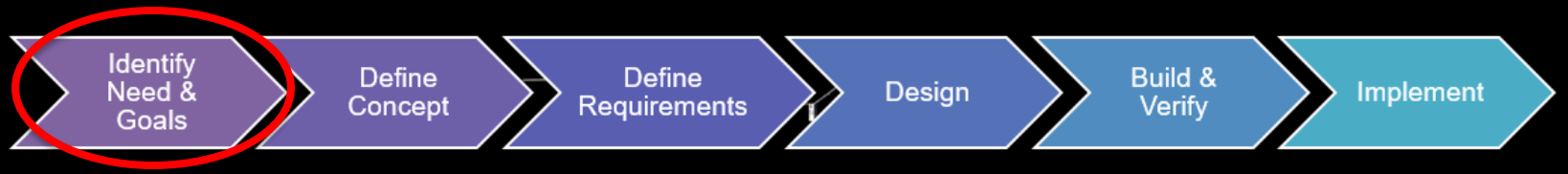
Need & Goals – BioNutrients-2

Need of BioNutrients Project

Enable rapid, safe & reliable in-place production of dietary nutrients using minimal mass, power & volume for long duration missions.

Goals of BioNutrients-2

1. Enable growth of yeast organisms
2. Produce targeted beta carotene on the International Space Station (ISS)
3. Reduce mass & volume as compared to the BioNutrients-1 Payload



Role of the Concept of Operations

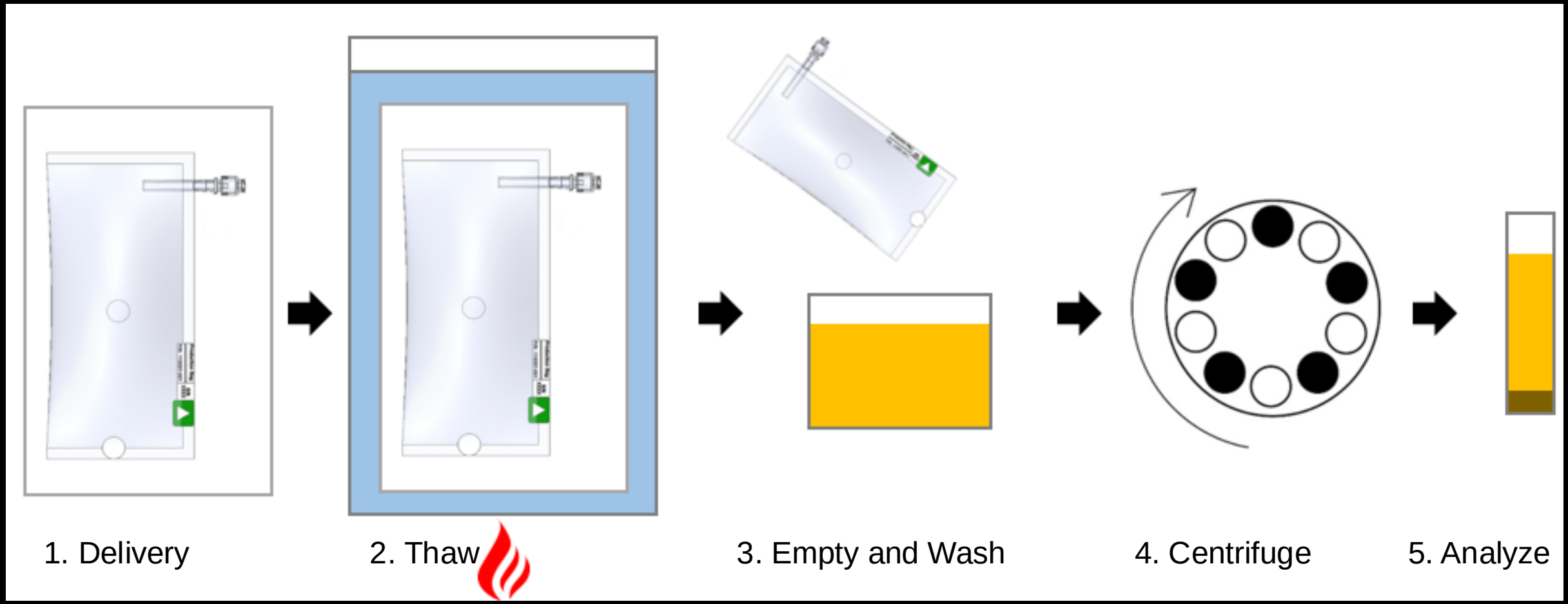
NPR 7123.1 Description of Concept of Operations

- Describes overall high-level concept of how system will be used to meet stakeholder expectations, usually in a time sequenced manner.
- Describes the system from an operational perspective & helps facilitate understanding of system goals.
- Stimulates development of requirements & architecture.
- Serves as the basis for subsequent definition documents & provides the foundation for the long-range operational planning activities.
- Provides the criteria for the validation of the system.

Mission Segments - BioNutrients-2

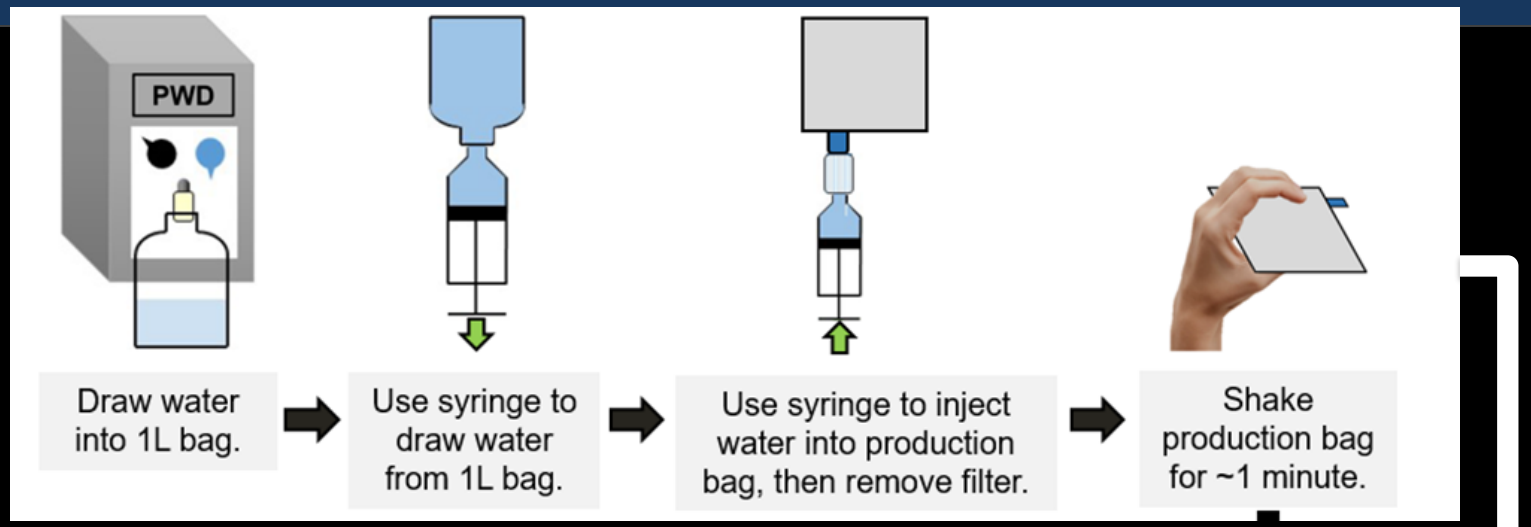
- Launch segment: NG-18 to ISS, soft-stowed at room temperature.
- Space segment: Experiment conducted on ISS. Samples are hydrated, incubated, then frozen & returned to Earth.
- Ground segment: Scientists & engineers watch experiment initiation in real-time then monitor temperature from ground.
- User segment: Scientists receive frozen samples, process samples and analyze. Scientific research is published.

Begin with the End in Mind - User Segment - BioNutrients-2

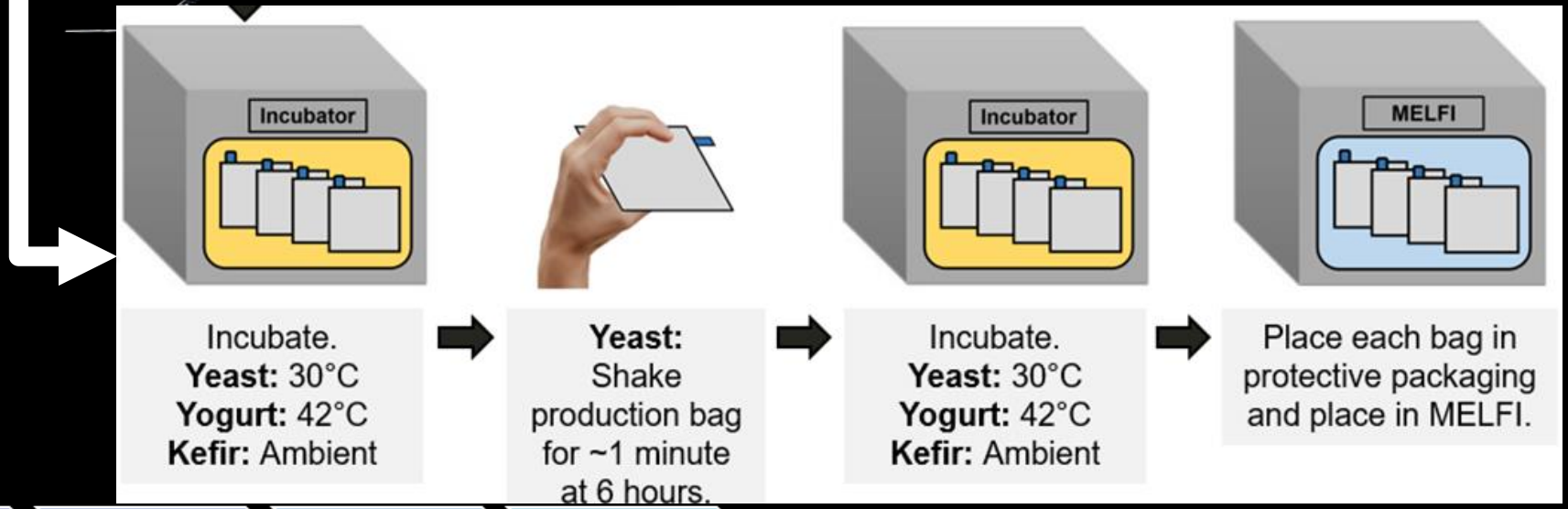


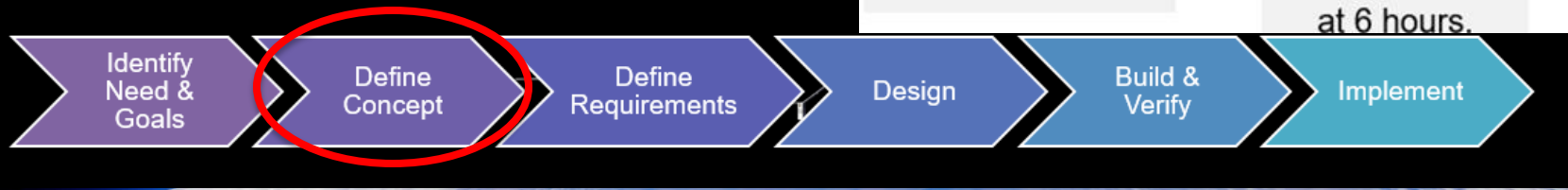
Identify Need & Goals | Define Concept | Define Requirements | Design | Build & Verify | Implement

Space Segment & Ground Segment - BioNutrients-2



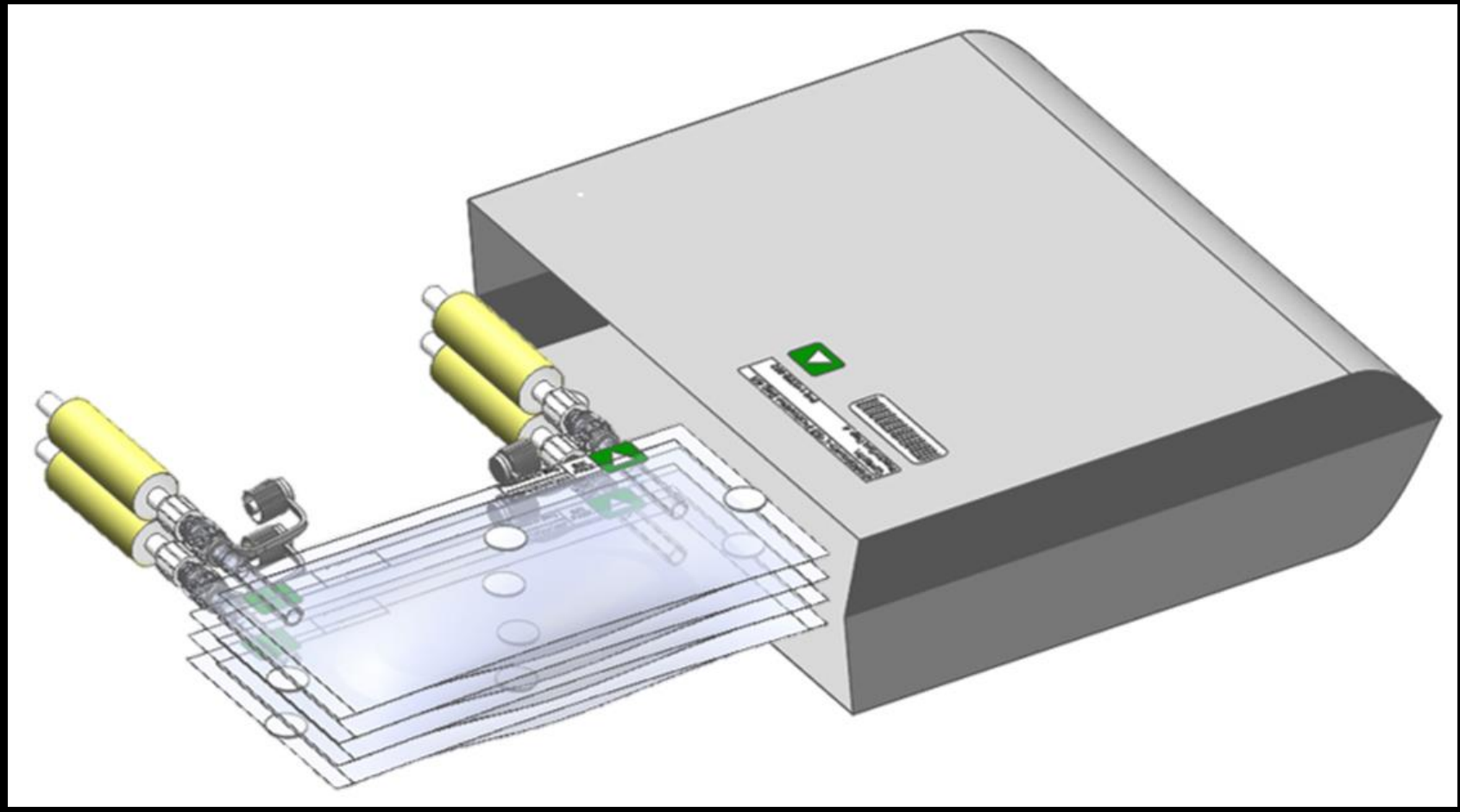
Ground Segment: Scientists & engineers watch experiment initiation in real-time then monitor temperature from ground.





Launch Segment - BioNutrients-2

- NG-18
- Samples soft-stowed
- Room (ambient) temperature
- Protected from oxygen & moisture



Identify Need & Goals | Define Concept | Define Requirements | Design | Build & Verify | Implement

Begin with the End in Mind – Requirements – BioNutrients-2

Recall goals:

1. Enable growth of yeast organisms
2. Produce targeted beta carotene on the International Space Station (ISS)
3. Reduce mass & volume as compared to the BioNutrients-1 Payload

Information/data, in the form of a publication, is part of the end product.

- What type & quantity of data is needed to answer research questions?
- To obtain that type & quantity of data from sample processing, what quantity, repetition and quality of samples are needed?

- ≥ 12 replicate samples
- ≥ 30mL volume per sample
- ≥ 3µg beta carotene / mL of returned sample
- ≥ 1 mg dry cell weight per sample
- No microbial contamination

Begin with the End in Mind – Requirements – BioNutrients-2

Recall goals:

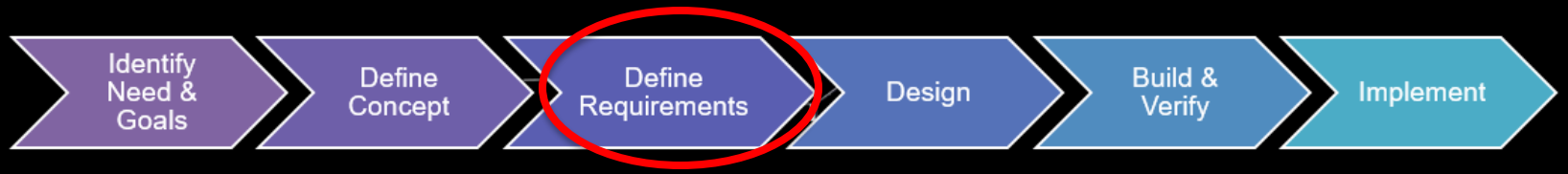
1. Enable growth of yeast organisms
2. Produce targeted beta carotene on the International Space Station (ISS)
3. Reduce mass & volume as compared to the BioNutrients-1 Payload

Demonstration of reduced resource use (mass & volume) is the other part of the end product.

For same starting sample size as BioNutrients-1, have:

- < 250 g sample container
- < 300mL total occupied volume

When identifying requirements, also plan how you will verify that design satisfies requirements (prior to implementation). For example, < 250 g sample container is verified by weighing an empty sample container.



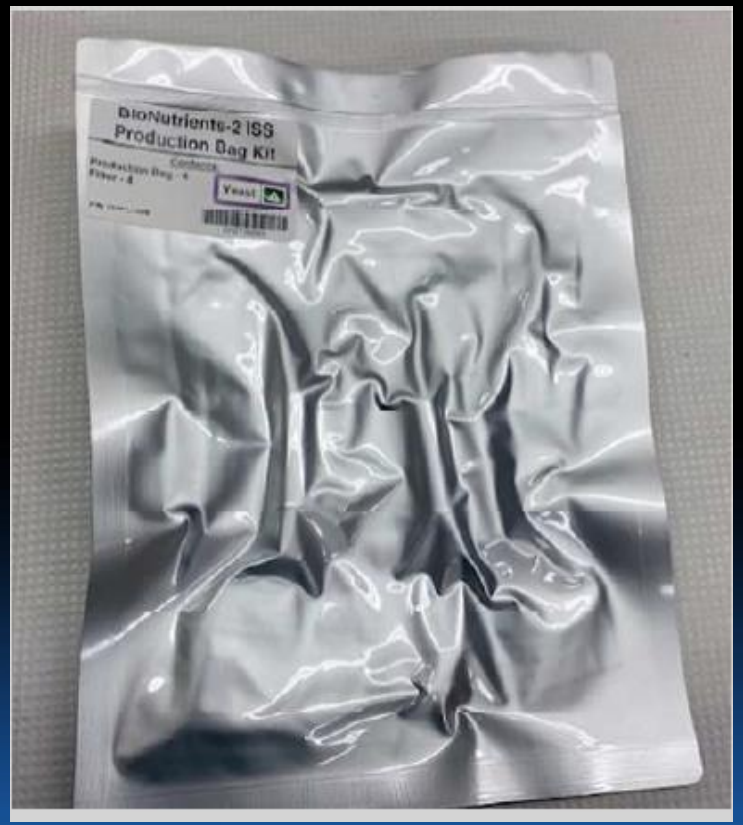
Design (Hardware) – BioNutrients-2

Production Bag

Needlefree Swabable Barb Valve
Capped with a non-Luer Thread Cover in ISS Production Bag configuration.
Description: 1/8" barbed fitting, female Luer-Lok, polycarbonate body and barb base, silicone stem

Fluorinated Ethylene Propylene (FEP) Bag
Manufacturer: Instant Systems
Two thicknesses: 3mil used for Yeast, 5mil used for Yogurt/Kefir
Description: 3mil FEP Film or 5mil FEP Film, 8.5" L x 3.25" W

Labels
P/N indicates thickness of bag and whether it was built in earth (-001) or ISS (-002) config.
Color-coded border indicates sample type
S/N range also indicates Sample Type



Identify Need & Goals → Define Concept → Define Requirements → Design → Build & Verify → Implement

Design (Experiment) – BioNutrients-2

Sample Hydration and Agitation

Sample Incubation

Sample Freezing

Build & Verify – BioNutrients-2

After hardware is fabricated, & sterilized, it is loaded with organism & growth media.

After organism & media loading, hardware assembly is completed.

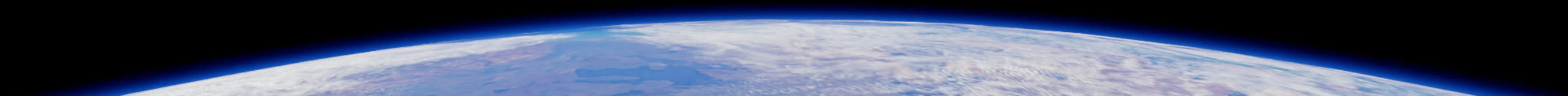
Implement – BioNutrients-2

Scientists & engineers are on-console during experiment operations in case of crew questions or anomalies.

Identify Need & Goals → Define Concept → Define Requirements → Design → Build & Verify → Implement

What are examples of a science missions?

- NASA's PUNCH Mission (Polarimeter to Unify the Corona and Heliosphere): This mission uses a constellation of four small satellites in low Earth orbit to make global, 3D observations of the Sun's corona, aiming to understand how mass and energy from the corona become the solar wind that fills the solar system. https://science.nasa.gov/mission/punch/
- PILOT (Plasma Imaging, LOcal measurement, and Tomographic experiment): This mission, designed to study the effects of the Sun on Earth's magnetosphere, involves a fleet of 34 satellites in two different orbits to measure the flow of cold, dense plasma into and out of Earth's magnetosphere. https://advancedspace.com/pilot-magnetosphere-science-mission-design/
- NASA's Dawn Mission: This mission was the first spacecraft to orbit two small bodies, asteroid Vesta and dwarf planet Ceres, allowing scientists to explore the environment in which planets formed. https://exploreintrosems.stanford.edu/news/aa-118n-how-design-space-mission-concept-execution
- Mars Moon Sampler: Phobos/Deimos Lunar Lander: This mission, part of the New Frontiers Class, aims to determine the origins of Phobos and Deimos, the moons of Mars, by returning samples to Earth. https://www1.grc.nasa.gov/facilities/compass-lab/designs-by-type/
- Space Launch System (SLS): SLS is a heavy-lift launch vehicle designed to enable future exploration goals, offering reduced mission time, increased mass margins, and increased payload volume. https://ntrs.nasa.gov/api/citations/20130013034/downloads/20130013034.pdf
- Artemis Program: The Artemis program is a series of missions, including Artemis X, that aims to deliver lunar surface logistics and enable long-term astronaut stays on the moon. https://en.wikipedia.org/wiki/Artemis_program



Questions?

www.nasa.gov/smallsat-institute/