Life Support Systems for the Space Environment

Basic Tenets for Designers
Rev. A
June 27, 2002

Dr. John Graf/JSC-EC3
Barry Finger/Honeywell
Katherine Daues/JSC-EC

When designing life support systems for the space environment or flight experiments and technologies intended to lead to the development of flight life support systems, designers should consider the following tenets as general guidance. While many other considerations must ultimately be taken into account when designing life support systems for the space environment, these fourteen tenets can be considered a starting point for new designers.

1. Safety is the number one priority of all flight hardware systems. In reviewing any hardware design or schematic, a good safety engineer will assume that every valve will leak, every electrical cable will short, every motor will seize (and overheat), and every sensor will relay a false signal. Additionally, a good safety engineer will assume that every design will suffer two failures simultaneously. Keep this in mind when designing hardware.

2. Reliability is closely related to safety and it is essential for space life support processes. The mechanical aspects of these systems must be designed to work flawlessly throughout their operational lifetime to ensure crew survivability.

3. A completely new set of design challenges emerges for the development of microgravity-compatible life support processes. The lack of buoyancy-driven convection is profound and impacts the design of processes that utilize multi-phase flow. Processes such as phase separation (solid, liquid, and gas) and heat transfer are of particular concern. Also, these challenges are not limited to liquid/gas interactions alone - the separation of loose particulate matter is also complicated by the lack of a dominant gravity vector. A design that operates in a single phase is less complex than a design that has two-phase flow. History has shown that any design that requires three phase operations with simultaneous handling of solids, liquids and gases will probably fail. This is a cautionary statement made to encourage careful thought before a researcher commits to a multiphase research project. Heat transfer and heat rejection is critically important, and critically expensive. Heat does not rise or dissipate well, and most hardware systems that generate appreciable amounts of heat are coupled to a circulation loop of cooled liquid. The heat rejection system's internal and external fluid lines, pumps, and heat exchangers represent a significant portion of

a flight environmental control system. Generally, too much heat is dissipated to the air in a flight environment.

4. Spacecraft life support processes are inherently "closed-chamber operations." With this ground-rule in place, the following always apply and cannot be overemphasized:
    a. Dilution is never the solution to pollution
    b. Everything that is utilized is a consumable
    c. Everything that is produced is a product (i.e. you can't ignore any waste product)

5. Hazardous gases are very difficult to handle, considering the safety engineer's assumptions that every valve leaks and every sensor gives faulty readings. For example, hydrogen lines are all operated at less than ambient pressure to promote in-leakage, and hydrogen is never stored or allowed to accumulate in any appreciable amount.

6. The waste streams that are processed in space flight applications are often very different than their terrestrial counterparts. For example, wastewater streams tend to have much higher concentrations of waste compared to traditional wastewater. Real metabolic streams are very much more complex and difficult to work with than chemical simulants. Historically, every space flight life support system that has operated flawlessly when subjected to chemical simulated sweat and urine, has failed the first time it has been challenged with real metabolic products.

7. Never underestimate the complexity of closed systems, or the importance of testing in closed systems. Integration and interaction with other systems cannot be ignored in the design and operation of spacecraft life support systems. To badly quote Newton, "for every action there is an equal, and opposite reaction." For example, coatings, off-gas products, and trace metabolic products have triggered entirely unexpected responses in a flight environment.

8. Simplicity in operation, maintenance, repair, and control system software is essential. Complex processes that require intensive human or machine oversight will almost never win out over those that require a minimum of these resources. Also, verifying, integrating, and changing software in a flight environment is often more expensive than the entire cost of design, development, manufacture, and testing of the physical hardware. The more modular and freestanding the software is, the better.

9. Maintaining a flight system is frequently more expensive than the designing and manufacturing the flight system. Designers need to list and consider the impacts of every limited life item that needs replacing. Designers need to list and consider any consumables (chemicals, filters, fluids, etc.) needed. If maintenance tasks are needed, note them and budget for them. If there are any calibration issues or tasks, note them and budget for them.

10. Material selection is important. All non-metallic materials need to be checked for off-gas response, and compatibility with an elevated oxygen environment. Making hardware with entirely metallic materials is desirable if the hardware can meet the stringent acoustic requirements.

11. Human factors and human interfaces are important to consider. The close proximity of humans and machines that is found within the confines of spacecraft requires that safety be designed into all aspects of the life support hardware. Hot surfaces, sharp edges, and exposed rotating equipment, are just a few examples of the types of hazards that must be avoided. Kick loads, switches that are easy to engage and offer positive feedback, repair strategy, designing cables that can be removed and connected without incident all seem easy and intuitive, but many flight hardware failures can be traced to human factors. Changes in crew posture in microgravity (affecting line of sight and reach), display orientation, and other visual cues should be considered in hardware and operations design. Consider human factors early in the design process.

12. Processes incorporated into space flight hardware have to be very mature, and very well understood. The performance envelope must be thoroughly mapped to minimize uncertainty.

13. A key driver in the design (and ultimately selection) of life support processes is the need to minimize the use of consumables. This is due to the tremendous costs associated with transporting mass from the Earth to low Earth orbit or beyond.

14. The scale of space life support processes is almost always smaller than that of terrestrial commercial processes. In fact, most terrestrial "pilot plants" are significantly larger than any conceivable near to mid-term space flight application.