Fenno RM. ***Man's milieu in space: a summary of the physiologic requirements of man in a sealed cabin.*** **JAM 1954; 25: 612–22.**

This paper considered the requirements for a closed system to sustain humans in space. The only earlier work of this type was associated with stratospheric balloon ascensions in the 1930s conducted by the U.S. Army Air Corps. In 1935, the helium balloon Explorer II carried two men in a sealed gondola to 22 km (72,395 ft), still the record at the time of this paper. The flight lasted just over 8 hours and the atmosphere in the gondola was replenished with O_2 and N_2, while water and CO_2 were absorbed by NaOH and temperature was actively regulated (1). In addition, recent experiments had shown that mice could be kept in a sealed container for 30 days when the system provided food, water, oxygen, and removal of CO_2 (6).

The Classic paper delineated the following life-support considerations:

- Oxygen replenishment using pressurized liquid O_2. Explorer II had used only 0.15 lb O_2/man/hour. Providing O_2 alone would simplify the system and O_2 toxicity would not be a problem as long as the cabin pressure was below 8.2 psi (above 15,000 ft equivalent).
- Cabin pressurization to the lowest practical level, allowing for a light hull structure. However, pressure had to be greater than 4.25 psi (below 30,000 ft equivalent) to avoid problems with decompression sickness.
- CO_2 absorption by biological, physical, or chemical methods. The most practical would be LiOH or a similar alkali absorption apparatus.
- Odor control by removing noxious odors and organics with activated charcoal filters.
- Water absorption to keep humidity as low as comfortably possible (35% was suggested).
- Thermal control to dissipate excess heat, since radiant energy would be continuously absorbed in space. A range of 50–75°F was considered, with 60°F being optimal.
- Circulation of cabin air to prevent development of CO_2 pockets in weightlessness.
- Cabin noise level below 70 dB.
- Radiation shielding as required. The radiation level in space was still unknown, with some experts predicting a safe level ($<$ 16 mrem/week) while others worried about the bioeffects of the recently discovered heavy nuclei (8).

The author concluded that "Space flight is a fact; space travel is not" and that further progress could not be made until engineers could produce a sealed cabin that met the requirements outlined in this paper.

Background and Comment

Following this report, the USAF School of Aerospace Medicine (USAFSAM) constructed a sealed space cabin simulator (12). The cabin had a volume of 2.80 m^3 (96 ft^3), room enough for an ordinary aircraft seat and a display panel to test subject performance. It had all of the systems described by Fenno, except that it maintained a 40% O_2 cabin atmosphere at 7.4 psi. Urine and condensed moisture were distilled to provide potable water. A manned simulation was performed for 24 hours in 1956. Two years later, Airman Donald F. Farrell completed a week in the simulator, receiving worldwide publicity (3). That was followed by the construction of a larger simulator with a volume of 10.75 m^3 that hosted two experiments in 1960, each with two occupants. The first used a pressure of 4.0 psi with 100% O_2 for 17 days, and the second 7.4 psi with 40% O_2 for 30 days. Measured variables included caloric intake, fluid intake and output, and O_2 consumption. There was no evidence of O_2 toxicity and no decrease in performance, but there were mild decrements in exercise capacity and mild dehydration due to a physiological diuresis. The two-man crews had no difficulty in maintaining an effective working relationship (5,13).

Fenno proposed that the sealed cabin be pressurized in the range of 4-8 psi and that it be replenished only with O_2, implying that its composition would gradually approach 100% O_2. In setting those parameters, the author failed to recognize the extreme danger of fire in a 100% O_2 atmosphere. That factor was considered in engineering the gondolas for the USAF's Man High balloons (1955–1958), which used a pressure of 5.8 psi with 60% O_2, 20% N_2, and 20% He (10,11), a design that was used safely on three flights, with Man High II reaching 101,516 ft on August 20, 1957. Unfortunately, the U.S. space program followed the 100% O_2 model (4). In 1961 the Soviet Union lost cosmonaut Valentin Bondarenko to fire in a 100% O_2 sealed-cabin simulator and they continued to design their spacecraft for a sea-level atmosphere (20% O_2 at 14.7 psi) (7). In 1962 the U.S. program experienced two dangerous fires in 100% O_2 research chambers, but no fatalities occurred until 1967 when the interior of the Apollo 1 capsule, undergoing a manned over-pressure test (100% O_2 at 16.1 psi) on the launch pad, was engulfed in flames with the loss of three astronauts. Just 3 days later, two USAFSAM technicians died in another 100% O_2 research chamber fire (9). Following investigation of these fires, Apollo launch procedures were changed to use 60% O_2 on the pad, transitioning to 100% O_2 during launch as cabin pressure decreased. The 5-psi cabin pressure was retained throughout the program (including Skylab) as it was inherent in the design of the capsules. However, later U.S. spacecraft, including the Shuttle and ISS, use a sea-level air atmosphere.

This Classic was the first paper in the open literature to address the range of requirements for a sealed cabin suitable for spacecraft. Although the author did not recognize the fire hazard associated with a high O_2 atmosphere, the rest of his assessment proved to be correct, as shown by the use of his parameters in early sealed cabins on all subsequent spacecraft. Among other things, Fenno was correct about CO_2 accumulation: cosmonauts on the poorly ventilated Mir space station occasionally encountered hypoxic CO_2 pockets and crews of the International Space Station are careful about entering small, closed compartments. A footnote to the paper stated that it was "from the Department of Space Medicine" at USAFSAM and acknowledged the "technical and editorial assistance" of H. Strughold, M.D., and H. G. Clamann, M.D. A literature search indicates that the author, a Major in the USAF Medical Corps, published only one other journal article in the field of Aerospace Medicine (2).

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DOI: 10.3357/ASEM.2910.2010

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(Required by 39 U.S.C. 3685)

1. Title of Publication: *Aviation, Space,and Environmental Medicine.*2. Publication No. 008-760. 3. Date of Filing: September 1, 2010. 4. Frequency of Issue: Monthly. 5. No. of Issues Published Annually: 12. 6. Annual Subscription Price: $225. 7. Complete Mailing Address of Known Office of Publication: Aerospace Medical Association, 320 S. Henry St., Alexandria, VA 22314-3579. 8. Same as #7. 9. Full Names and Complete Mailing Address of Publisher, Editor, and Managing Editor: Pubisher -- Aerospace Medical Association, 320 S. Henry St., Alexandria, VA 22314-3579. Editor -- Frederick Bonato, Ph.D., P.O. Box 2348, Salisbury, NC 28145-2348. Managing Editor -- Pamela C. Day, B.A., Aerospace Medical Association, 320 S. Henry St., Alexandria, VA 22314-3579. 10. Owner: Aerospace Medical Association, 320 S. Henry St., Alexandria, VA 22314-3579. 11. Known Bondholders, Mortgages, and other Security Holders Owning or Holding 1 Percent or More of Total Amount of Bonds, Mortgages, and Other Securities: None. 12. For Completion by Nonprofit Organizations Authorized to Mail at Special Rates: The purpose, function, and nonprofit status of this organization and the exempt status for Federal income tax purposes has not changed during the preceding 12 months.
13. Publication Name: *Aviation, Space, and Environmental Medicine.*
14. Issue Date for Circulation Data: 08-20-2010.

15. Extent and Nature of Circulation:	Ave. No. Copies Each Issue During Preceding 12 Months	No. Copies of Single Issue Published Nearest Filing Date
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