Technical Memorandum DS-12

# Twenty-Four (24) Man-Hour Test

# of

# ALVIN's Environmental System

by

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1. ALVIN's specifications call for a 48 man-hour environmental system capability. To check this, a 24 man-hour test was run as follows: Two successive test periods of six (6) hours each with a two (2) man crew inside the pressure hull. The break after six (6) hours was solely to change the crew. It was felt that this 24 man-hour exercise would be adequate to judge the system's 48 man-hour capability, particularly since one cannister of LiOH was used and the submarine will normally carry two (2).

2. A test of ALVIN's environmental control system was conducted 22 June 1964, at Woods Hole Oceanographic Institution.

3. Hardware -- (all of which is located inside the pressure hull with the exception of the ammeter)

   a. Air regeneration unit
      1) blower, 28 VDC
      2) activated carbon cartidge (10-16 mesh granules)
      3) Fiberglas filters
      4) one cannister with 6.4 pounds (4-16 mesh granules) of anabydrous lithium hydroxide (LiOH). Cannister MIL-E-21004.

   b. Oxygen supply
      1) cylinder - 2250 psi. operating pressure 730 $in^3$ volumetric capacity
      2) regulator with 1800 psi. relief manufactured by Scott

   c. Combination oxygen, carbon dioxide analyzer manufactured by Thermco
      1) 28 VDC
      2) utilizes magnetic properties of oxygen and thermal conductivity of carbon dioxide

   d. Portable analyzers
      1) carbon dioxide (DAVIS TOXIC GAS DETECTOR, MODEL 1 with vials)
      2) oxygen (BECKMAN D-E ANALYZER)

   e. Temperature and humidity gauge
      1) Manufactured by ABBEON, INC.
      2) Ranges: 0-100% humidity
         -10 to 190°F temperature

   f. Marine barometer
      1) airguide ship's barometer
      2) Range: 28-31 inches mercury

g. Aircraft altimeter
   1) standard sensitive type

h. Voltmeter
   1) 30 VDC

i. Ammeter

4. System Operation -- Oxygen ($O_2$) is bled into the hull from its cylinder via a pressure regulator designed to provide a minimum flow when it's shut off and the cylinder valve is open. This system can also be manually regulated. The air regeneration unit absorbs both water vapor and carbon dioxide ($CO_2$) from the air driven through it by its 28 VDC blower. A flue on the side of this unit can be used to adjust the air flow. LiOH granules are the sole absorbing medium, the governing equations being:

$$LiOH + H_2O = LiOH \cdot H_2O$$

$$2LiOH + CO_2 = Li_2CO_3 \cdot H_2O$$

Activated carbon filters incorporated in this unit remove undesirable odors. The combination $O_2$ and $CO_2$ analyzer monitors existing $O_2$ and $CO_2$ concentrations in the hull. The portable analyzers were present as back ups. A marine barometer and aircraft altimeter indicate instantaneous atmospheric pressure. An internal voltimeter and an external ammeter indicate the load on the external fifteen (15) cell, 30 VDC lead-acid energy source, which supplied the blower, the combination analyzer, and the interior lights. The operation of this whole system as a unit is quite simple. The atmospheric pressure and $O_2$ and $CO_2$ concentrations must be maintained within given limits while bleeding in $O_2$ and absorbing $CO_2$ and water vapor. For this test we set the following limits:

| | |
|---|---|
| $O_2$ | 18 - 25% |
| $CO_2$ | 2% maximum |
| atmosphere | 28.5 - 31 inches of mercury |

Whenever these limits were exceeded the test was to be stopped and the hull evacuated immediately.

5. Test Conditions -- Prior to ALVIN's delivery to Woods Hole, Litton ran a successful twelve (12) hour canary toxicity check on the inside of the pressure hull. For our environmental test, a sound-powered telephone was the prime means of communications with the

participants, and a two man watch was maintained outside the hull throughout the test. Also, conditions inside the hull would be continuously observed through its windows. During this test, the pressure hull was separate from the rest of the vehicle, on a supporting stand. Steps were taken to cover any possible emergency which might arise during the test*; all participants made a conscious effort to "dry out" prior to getting in the hull because no relief facilities were provided. Fortunately, no problems arose. The combination oxygen and carbon dioxide analyzer had been run in and calibrated previously by Litton, and they had experienced some problems, that time finally overcame. However, during our preliminary checkout, the oxygen portion of the unit wouldn't function properly, so we reverted to our portable analyzers, with periodic checks on the combination analyzer.

*Including a fire extinguisher and SCUBA inside the hull, and the local fire department standing by.

6. Recorded Data and Comments

a. The hatch was closed at 1239 on June 22, 1964. The occupants for the first six (6) hours were William M. Marquet of WHOI, and Darrel Nelson of A.S.D., Litton Industries.

b. The $CO_2$ portion of the combination analyzer was operating, the $O_2$ bottle and regulator were open, the blower was running with the flue closed, there was no altimeter in the hull during the the first six (6) hours, and no readings were taken before the hatch was closed except for the barometer which read 30.00 inches.

| TIME | COMB. ANALYZER $CO_2$ (%) | PORTABLE $CO_2$ (%) | PORTABLE $O_2$ (%) | $O_2$ CYLINDER PRESS (PSI) | TEMP. (F°) | RELATIVE HUMIDITY (%) | BARO-METER (IM.Hg) | ALTIMETER READING (FT.) | BLOWER VOLTS | BLOWER AMPS |
|---|---|---|---|---|---|---|---|---|---|---|
| 1239 | | | | | | | | | | |
| 1244 | 0 | | 20.3 | 1340 | 70 | 87 | 30.84 | | 28 | 4.2 |
| 1300 | 0 | | 20.4 | 1300 | 72.5 | 90.2 | 31+ | | 28 | 4.1 |

c. Very rapidly, control of the atmospheric pressure was lost, and the reading went right off scale. At this time we disregarded our atmospheric pressure limitations as long as the participants reported and looked to be in no trouble. The $O_2$ regulator was shut off, and data reports were investigated every five (5) minutes until the situation was well under control.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1307 | | | 20.3 | | | | 31+ | | | |
| 1315 | 0 | | 20.4 | | 74 | 90.1 | 31+ | | 28 | 4.15 |

d. At this point the $O_2$ cylinder valve was shut off.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1326 | | | 20.1 | | | | 31+ | | | |
| 1330 | 0 | | 20.0 | | 74 | 89.0 | 31+ | | 28 | 4.15 |
| 1340 | | | 19.8 | | | | 31.00 | | | |

e. The atmospheric pressure was just coming back within limits. Note that all this time the combination analyzer indicated 0% $CO_2$ level. Moisture was first noticed on the inside lower hull at 1330. With the flue open, the blower drew 4.1 amps at 27.9 VDC. When closed it drew 3.9 amps at 28.1 VDC.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1345 | 0 | | 19.6 | | 75 | 88.7 | 30.99 | | 27.9 | 4.1 |
| 1350 | | 0.55 | 19.3 | | | | 30.96 | | | |

f. This was the first portable $CO_2$ reading, indicating a definite difference between it and the combination unit. We had agreed to take portable $CO_2$ readings once every hour.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1400 | 0 | | 19.2 | | 75.5 | 90.0 | 30.93 | | 27.9 | 4.1 |

g. The humidity gauge was momentarily fluctuating ±5%.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1415 | | | 19.0 | | 75.5 | 88.5 | 29.52 | | 27.9 | 4.1 |

h. Just prior to this the barometer reading was lowered 1.34 inches, to 29.59, to facilitate its control, as the barometer scale ran from 28.5 to 31.0 inches. This simulated a reading of 29.50 inches at 1244, instead of the 30.84 inches recorded.

| TIME | COMB. ANALYZER $CO_2$ (%) | PORTABLE $CO_2$ (%) | PORTABLE $O_2$ (%) | $O_2$ CYLINDER PRESS (PSI) | TEMP. (F°) | RELATIVE HUMIDITY (%) | BARO-METER (IM.Hg) | ALTIMETER READING (FT.) | BLOWER VOLTS | BLOWER AMPS |
|---|---|---|---|---|---|---|---|---|---|---|
| 1420 | | | 18.9 | 1300 | | | | | | |

i. The $O_2$ cylinder was opened, with the regulator valve still off.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1430 | | | 18.8 | 1300 | 76.0 | 88.5 | 29.50 | | 27.9 | 4.1 |

j. Note that during this ten (10) minute period neither the $O_2$ concentration, nor the barometer indicated a small $O_2$ bleed through the closed regulator. At this time the $O_2$ regulator was opened one quarter of a turn.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1445 | 0 | 0.7 | 19.0 | 1270 | 76.0 | 88.0 | 29.54 | | 27.9 | 4.0 |

k. The flue was closed on the air regeneration unit and the combination analyzer was turned off.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1500 | | | 19.2 | 1250 | 76.0 | 89.8 | 29.68 | | 28.0 | 3.9 |
| 1510 | | | 19.7 | | | | 29.74 | | | |
| 1515 | | | 19.8 | 1210 | 77.0 | 90.7 | 29.76 | | 27.9 | 3.9 |
| 1530 | | | 20.0 | 1180 | 77.5 | 90.0 | 29.85 | | | |

l. Commenced charging the 30 VDC battery. Initial closed circuit reading was 29.4 VDC.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1539 | | 0.7 | | | | | | | | |
| 1545 | | | 20.0 | 1160 | 78.0 | 90.0 | 29.89 | | 29.5 | 4.2 |

m. Moisture on inside of hull had now reached the top of the forward window.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1600 | | | 20.2 | 1150 | 78.0 | 89.0 | 29.94 | | 29.7 | 4.25 |
| 1615 | | | 20.3 | 1120 | 78.0 | 91.0 | 30.02 | | 29.8 | 4.25 |
| 1630 | | | 20.7 | 1100 | 78.0 | 90.2 | 30.08 | | 30.0 | 4.3 |

n. The $O_2$ regulator was shut off.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1640 | 0.5 | | | | | | | | | |
| 1645 | | | 20.9 | 1070 | 78.0 | 91.0 | 30.14 | | 29.9 | 4.3 |

o. The $O_2$ cylinder was shut off. Note that this time the $O_2$ concentration and the atmospheric pressure all indicated an $O_2$ flow through the closed regulator. (Note also the $O_2$ cylinder pressure indicated same.)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1700 | | | 20.8 | | 79.0 | 89.9 | 30.14 | | 30.2 | 4.3 |
| 1715 | | | 20.2 | | 79.5 | 90.5 | 30.05 | | 30.2 | 4.3 |
| 1730 | | | 20.1 | | 80.0 | 89.6 | 30.03 | | 30.3 | 4.4 |
| 1745 | | 0.7 | 19.9 | | 80.0 | 88.4 | 30.01 | | 30.5 | 4.4 |
| 1800 | | | 19.5 | | 80.0 | 89.0 | 29.92 | | 30.4 | 4.4 |
| 1815 | | | 19.2 | | 80.0 | 89.0 | 29.85 | | 30.5 | 4.4 |
| 1830 | | | 19.0 | | 80.0 | 89.2 | 29.80 | | 30.5 | 4.4 |
| 1837 | | 0.6 | 18.8 | | 81.0 | 89.0 | 29.78 | | 30.6 | 4.4 |

| TIME | COMB. ANALYZER $CO_2$ (%) | PORTABLE $CO_2$ (%) | PORTABLE $O_2$ (%) | $O_2$ CYLINDER PRESS (PSI) | TEMP. (F°) | RELATIVE HUMIDITY | BARO-METER (IM.Hg) | ALTIMETER READING (FT.) | BLOWER VOLTS | BLOWER AMPS |
|---|---|---|---|---|---|---|---|---|---|---|

w. The combination analyzer was turned on for practice, along with the battery trickle charge.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 2345 | | 19.5 | 725 | 83.0 | 94.0 | 29.92 | -380 | 30.1 | 4.6 |

x. The $O_2$ cylinder and regulator were shut off.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 2400 | 0.5 | 19.5 | | 83.0 | 93.0 | 29.89 | -360 | 30.1 | 4.6 |
| 0015 | | 19.0 | | 94.0 | 94.0 | 29.76 | -225 | 30.25 | 4.6 |
| 0030 | | 18.5 | 725 | 84.0 | 93.0 | 29.72 | -150 | 30.4 | 4.6 |

y. The $O_2$ cylinder was opened with the regulator on one quarter turn, and the combination analyzer was secured along with the trickle charge.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0045 | | 18.9 | 700 | 84.0 | 92.5 | 29.74 | -190 | 30.0 | 2.6 |
| 0100 | 0.55/0.45 | 19.0 | 675 | 84.0 | 92.5 | 29.76 | -220 | 29.8 | 2.6 |

OPEN HATCH

Z. The test was completed at 0100, 23 June 1964, and the hatch was opened. During the whole test we had economized on the portable $CO_2$ analyzer vials and used both ends of each one. It was possible the second reading was high each time. Thus the two readings at 0100, the higher reading being the used vial, the lower one the new vial.

| TIME | COMB. ANALYZER $CO_2$ (%) | PORTABLE $CO_2$ (%) | PORTABLE $O_2$ (%) | $O_2$ CYLINDER PRESS (PSI) | TEMP. (F°) | RELATIVE HUMIDITY | BARO-METER (IM.Hg) | ALTIMETER READING (FT.) | BLOWER VOLTS | BLOWER AMPS |
|---|---|---|---|---|---|---|---|---|---|---|

p. At this time the hatch was opened, Marquet and Nelson having finished their six (6) hours. They were replaced by H. Learnard and M. McCamis, both of WHOI. The hull was ventilated, an aircraft altimeter was added to the instruments, and the original LiOH cannister remained in the air regeneration unit. A trickle charge continued on the 30 VDC battery package. The barometer was reset to 29.5 inches, the altimeter zeroed, and the $O_2$ cylinder and regulator were shut off. In this manner, with the hull freshly ventilated, we hoped to control the atmospheric pressure better initially. The hatch closed at 1900, with the combination analyzer remaining off.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1900 | | 20.0 | | 79.0 | 85.0 | 29.68 | -125 | 31.35 | 2.9 |
| 1915 | | 19.5 | | 79.5 | 90.2 | 29.76 | -175 | 31.36 | 2.9 |
| 1930 | | 19.0 | 1070 | 80.0 | 93.0 | 29.72 | -150 | 31.5 | 2.9 |

q. The $O_2$ cylinder and regulator were opened. With the interior lights and the air regeneration unit shut off, the battery load was 2.6 amps at 31.7 VDC.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1945 | | 19.5 | 1050 | 80.0 | 94.0 | 29.75 | -200 | 31.68 | 2.6 |

r. The $O_2$ cylinder and regulator were shut off.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 0.6 | 18.8 | | 80.5 | 94.5 | 29.66 | -100 | 31.5 | 2.9 |
| 2010 | | 18.5 | | | | 29.62 | | | |
| 2015 | | 18.5 | 1050 | 81.0 | 96.0 | 29.60 | -25 | 31.5 | 2.9 |

s. The $O_2$ cylinder was opened with the regulator on one quarter turn. The battery charge was secured at 2023.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 2030 | | 18.5 | 1025 | 81.0 | 95.0 | 29.61 | -25 | 30.0 | 2.6 |
| 2045 | | 18.8 | 1000 | 8.15 | 99.0 | 29.64 | -75 | 29.8 | 2.6 |

t. The $O_2$ regulator was opened completely.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 2100 | 0.65 | 18.9 | 975 | 81.0 | 94.8 | 29.67 | -125 | 29.8 | 2.6 |
| 2115 | | 19.0 | 950 | 81.0 | 95.5 | 29.71 | -180 | 29.75 | 2.6 |
| 2130 | | 19.5 | 925 | 81.0 | 96.0 | 29.76 | -225 | 29.70 | 2.6 |
| 2145 | | 19.5 | 900 | 81.0 | 93.0 | 29.79 | -250 | 29.70 | 2.6 |
| 2200 | 0.55 | 19.8 | 875 | 81.0 | 96.0 | 29.83 | -300 | 29.60 | 2.6 |

u. The $O_2$ cylinder and regulator were shut off.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 2215 | | 19.0 | | 83.0 | 96.5 | 29.82 | -250 | 29.49 | 2.6 |
| 2230 | | 18.6 | 870 | 83.0 | 94.2 | 29.68 | -150 | 29.30 | 2.8 |

v. The $O_2$ cylinder was opened with the regulator on one quarter turn.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 2245 | | 18.8 | 850 | 83.0 | 96.0 | 29.71 | -160 | 29.25 | 2.8 |
| 2300 | 0.8 | 18.8 | 825 | 83.0 | 95.0 | 29.70 | -130 | 29.20 | 2.8 |
| 2315 | | 19.0 | 800 | 83.0 | 93.0 | 29.70 | -175 | 29.20 | 2.8 |
| 2330 | | 19.3 | 775 | 83.0 | 95.0 | 29.81 | -300 | 29.6 | 4.6 |

7. Conclusions

a. Our twelve (12) hour test, with two crew members throughout, resulted in a 24 man-hour check of ALVIN's environmental system. During this period, thirty (30) percent of the oxygen available in its cylinder was consumed. Approximately, this amounted to 19.5 cubic feet of the 64.7 cubic feet abailable at 2250 psi. But, the $O_2$ regulator has a pressure relief at 1800 psi, which means only 79 percent, or 51 cubic feet of our oxygen capability is being utilized. This we intend to correct. In terms of the vehicle's 48 man-hour specification, the oxygen system, with the 1800 psi relief, should be capable of 63.2 man-hours. Once this is corrected, the existing oxygen cylinder will have an 80 man-hour capability.

b. Differences in individual physiology will naturally cause differences in oxygen consumption between any two persons. The first two crew members, 130 pounds, 5 foot 4 inches, and 185 pounds, 5 foot 8 inches, consumed only twelve (12) percent of the oxygen, or 7.8 cubic feet. The second two crew members, 170 pounds, 5 foot 8 inches and 200 pounds, 6 feet, consumed eighteen (18) percent of the oxygen, or about 11.5 cubic feet. Using the latter figures, the oxygen has a 52.5 man-hour capability with the 1800 psi relief, and 66.5 man-hours when this restriction is removed. These figures are probably more accurate than those in paragraph a., because the second two crew members are prospective ALVIN pilots.

c. As indicated by the data, throughout the 24 man-hours of this test, the $CO_2$ concentration was kept between 0.5 and 1.0 percent, with some reliability. During this period the one LiOH cannister gained three (3) pounds, from 8.2 to 11.2 pounds. The design specifications predicted two (2) cannisters would adequately handle the absorpiton of $CO_2$ and water vapor produced by two (2) men in a 24 hour period, based upon the equations of paragraph 3. According to tests run by the U.S. Air Force School of Aviation Medicine, in a closed chamber LiOH granules will absorb 47.3% and 33.3% of their own weight in $CO_2$ and water vapor, respectively, before adversely affecting their absorption capability. In view of our results, and this previous experience, the three (3) pound gain of one LiOH cannister (6.4 pounds LiOH granules, net) is well within the design specifications.

In further comment in the air regeneration unit, it must be mentioned that, in spite of the water vapor absorbant, the humidity hovers around 100 percent. This we expected. The activated carbon filters were very effective. Numerous times, when $O_2$ was not being bled into the hull, participants smoked. Within half an hour after extinguishing the cigarette, there were no noticeable traces of smoke remaining. Finally, it appears the flue should be left closed for best $CO_2$ scrubbing, especially with two or more normal to large

crew members. The highest $CO_2$ concentration (0.8%) during the test followed a period with the flue open.

d. It was found practical to expect the crew members to be forewarned adequately of higher than normal $CO_2$ concentrations, by their own senses. The participants during the second six hour stint commented on either a noticeable increase in breathing speed, or abnormal breathing tension, when the $CO_2$ concentration was a maximum.

e. As a result of this test, the combination analyzer has been removed from ALVIN permanently. The Davis $CO_2$ portable analyzer, using the vials, will be replaced by a Beckman model which is independent of any reusable or throw away device. These Beckman portable analyzers are judged more than adequate for this function.

f. The $O_2$ regulator proved to be a weak link in the system also, because little about its automatic function was known or understood at the time of the test. As a result, the $O_2$ system was operated manually quite simply, throughout the test. Its automatic function will be evaluated during ALVIN's sea trials.

## 8. References

a. Basic Scuba, F.M. Roberts