There were instances of increased levels of fungi in the air which coincided with peaks found associated with the aquanauts and the habitat walls. The peaks of fungi in the air during days 0 through 12, 19 through 29, 29 through 35, 46 through 50, and 50 through 59 all coincided with at least five peaks occurring at these same times in the mycological results. The peaks occurring between days 39 through 43 coincided with the results obtained from the wet lab wall, the location of the air sampler. Thus there was a close association between the incidence of fungi in the air and on the personnel.

There were no major medical complaints from the aquanauts; thus revolutionary changes in the microbial population were not expected. The only medical problems of consequence were the ear infections. Their frequency did not seem aggravated by the environmental conditions imposed by the program. Such ear infections are common among divers working in warm and humid conditions. The most common infecting organism in the ears of the divers is *Pseudomonas*, the same organism found to produce infection in two aquanauts and possibly a third. Fungi did not appear to be involved in the ear infections in the Tektite I program.

There were no prominent changes in the indigenous microbial population of the aquanauts. The only exception was the ear infection and skin as noted above.

The microbial carrier state of the aquanaut did not play a part in the transmission of disease in the Tektite I program. This is borne out by the *Staphylococcus* carrier study and the evidence that *Candida* and *Proteus* remained associated with a single individual throughout the program.

The microbial population did not build up on the walls of the habitat during the 59 days of the study. The sample sites had not been swabbed prior to obtaining the sample; thus the sample represented the microflora of the wall over an increasingly longer period of time. This microflora was in a state of flux, with new organisms continually becoming associated with the wall surface, while the older organisms were dying.

The level of coliform organisms from the disposal of sewage into the environment did not attain a level sufficient to become a health hazard to the aquanauts.

Conditions imposed in maintaining the habitat did not induce a latent virus infection, nor did the aquanauts acquire any demonstrable virus infection from the marine environment.

The answers to the questions posed at the beginning of the program show that the prolonged application of the environmental conditions and aquanaut interactions in the Tektite I program did not result in any unusual microbiological hazard. The possible intrusion of a marine organism into the habitat and its establishment was of interest and may present a problem in future long-term studies of this type. Ear infections are common to this type of program and will probably remain so until an adequate prophylactic remedy is developed.

A3.4.11 Acknowledgments

Andre B. Cobet and John P. Hresko, Naval Biological Laboratory

Thanks are extended to the technical staff at the Naval Biological Laboratory for the prompt and efficient completion of the numerous details involved in this study. Particular thanks are also extended to Mr. Steve Dunn for the contributions he made at the on-site facility at St. John Island.

A3.5 Respiratory and Pulmonary Studies

A3.5.1 Objectives, Rationale, and Procedures

C. J. Lambertsen, Institute for Environmental Medicine,
University of Pennsylvania, Philadelphia, Pennsylvania

Detailed and varied studies of pulmonary function and respiratory control were conducted to determine the degree to which chronic exposure to a high-density atmosphere with a high partial pressure of inspired nitrogen would modify the mechanical properties of the lungs, the efficiency of pulmonary air movement, the exchange of gas across the pulmonary capillary membrane, and the reactivity of the control system which regulates respiration.

The lungs, the alveolar membrane, and the respiratory tract represent the interfaces between man and his gaseous environment. Gases in an artificial atmosphere such as is employed in diving can affect respiration through local or systemic physiological or toxic effects of individual respired gases, through acute stresses such as respiratory resistance due to increase in gas density at high pressure, and through adaptations or deteriorations resulting from prolonged exposure to any of these influences.

The experimental design for the biomedical studies of Tektite I took into specific account the known and postulated effects of exposure to a nitrogen-oxygen atmosphere at increased ambient pressure. Considerations which guided the choice of atmosphere and the studies to be performed were as follows:

- At the planned working depth of nearly 50 feet of sea water, respiration of air (20.94% oxygen in nitrogen, with traces of rare gases) would be expected to induce pulmonary and probably other forms of oxygen toxicity over the course of several days.

- By maintaining an oxygen percentage at the working depth low enough to provide an inspired oxygen partial pressure equivalent to the natural oxygen pressure in air at sea level, all forms of oxygen poisoning should be preventable.

- The increased gas density at the working depth would result in an increase in pulmonary airway resistance and in work of respiration. The degree of, consequences of, and adaptations to this respiratory stress were to be determined.

- Since nitrogen is largely an inert gas, it is unlikely that even high nitrogen pressures should exert toxic effects upon the pulmonary capillary membrane. However, since increased airway resistance can conceivably indirectly alter gas exchange across the pulmonary capillary membrane by inducing pulmonary edema, studies of gas diffusion across the alveolar membrane were included.

- Because the nitrogen in air has demonstrable narcotic properties at high partial pressures, sustained exposure to increased pN_2 was conceived as potentially depressing the respiratory control mechanisms. This, together with the possibly additive influences of adaptations to a sustained increase in work of breathing, led to measurement of the overall reactivity of the carbon dioxide-responsive components of respiratory control.

The control measurements, the pulmonary monitoring throughout the exposure, and the detailed postexposure measurements were incorporated in the study to provide a basis for evaluating whether the prolonged shallow exposure to high-density, high-nitrogen pressure was in fact thereafter to be considered safe for practical operations.

The aquanauts were subjected to meticulous clinical evaluation in parallel with study of respiratory and pulmonary functions. Since participation as physiological subjects required close familiarity with the measurement procedures to be employed, each aquanaut received preliminary indoctrination and training for his part in obtaining the desired information.

For the specific studies that would be conducted repeatedly undersea during the exposure period, the subjects were trained to perform the measurements required. These included use of pulmonary-ventilation and intrathoracic-pressure recording apparatus for determining ventilation, esophageal pressure, pulmonary airway resistance, work of breathing, vital capacity, and maximal ventilatory volume. This training made it possible to provide for the periodic measurement needed to assure early detection of any abnormalities of function and to do so without imposing direct contact with other individuals.

For those studies done only before and after exposure a team of investigators conducted control measurements at the University of Pennsylvania's Institute for Environmental Medicine. The same team then transported the apparatus to the base camp for postexposure studies.

The technique and quality of performance of respiratory and pulmonary measurements during the undersea phase was monitored by having two of the investigators from the Institute for Environmental Medicine also serve as medical monitors at the diving site. Performance and recording by the subjects was observed in detail by closed-circuit TV. Recordings made in the undersea habitat were transmitted to the Institute for analysis, and the results were reported to the on-site monitors.

A3.5.2 Respiratory Control Study

J. G. Dickson, R. Gelfand, and C. J. Lambertsen, Institute for Environmental Medicine, University of Pennsylvania

A3.5.2.1 Specific Objective

The specific objective of the respiratory control study was to determine whether the combined effects of increased respiratory work and inert gas narcosis produced by continuous, prolonged respiration of a nitrogen-oxygen atmosphere at more than twice normal atmospheric density leads to altered respiratory response to carbon dioxide. To determine this, pre- and postexposure measurements were made of frequency, depth, and minute volume of respiration during inhalation of 0, 2, 4, and 6% carbon dioxide in 21% oxygen under resting, stable conditions.

A3.5.2.2 Methods

The apparatus employed for the measurement of the respiratory parameters and for gas administration in this study was functionally equivalent to that employed for studies of respiratory depressant effects of narcotic drugs in man.* This apparatus was first assembled in Philadelphia and employed there for the control measurements. Subsequently the entire apparatus was transported to the diving site for the postdive measurements.

Inspired gas, supplied premixed from 2000-psi cylinders, was reduced to 50 psig by two-stage regulators (Oxweld type R-65). A demand valve (Mine Safety Appliances 10-81070) provided control of inspired gas to the subject via a low-dead-space (25-cc), plastic, two-way valve. The volume of expired air was measured by a dry gasometer

*J. J. Downes, R. A. Kemp, and C. J. Lambertsen, "The Magnitude and Duration of Respiratory Depression Due to Fentanyl and Meperidine in Man," J. Pharmacol. Exptl. Therap. 158, 416-420 (1967).

(Parkinson-Cowan type CD-4) with inlet and outlet gas temperatures monitored by bimetal dial thermometers. Respirations were manually registered on a digital counter, and time was measured with a stopclock. End-tidal CO_2 tension was measured and recorded for each breath (Beckman Model LB-1 infrared CO_2 analyzer; Esterline-Angus Model AW recorder). Premixed gases, accurate to ±0.03% CO_2 by analysis (Scholander 0.5-cc analyzer) and stored in high-pressure cylinders, were used to calibrate the CO_2 analyzer.

End-tidal gas samples were selectively trapped in the measuring cell of the CO_2 analyzer by causing the inspiratory pressure change to activate a pressure-sensitive switch (Fairchild PSF 100) connected to an end-tidal alveolar gas sampler.* The switch initiated a sequence involving momentary activation of a solenoid valve, causing a sample of end-tidal gas (trapped distal to the expiratory valve in the two-way breathing valve) to be drawn into the CO_2 analyzer. Subsequent closure of the solenoid valve caused the end-tidal sample to remain in the analyzer until the succeeding expiration was completed.

Each subject was studied in duplicate on each of two days. The series therefore included duplicate exposures to 0, 2, 4, and 6% inspired CO_2. He was placed in a supine position and made to rest for a 30-minute period prior to administering the succession of gases for CO_2-response measurements. Rectal temperature was measured with a thermistor thermometer. Each point on a respiratory CO_2-response curve required a 15-minute period of gas administration which was composed of two periods; an initial 10-minute segment was used to permit the respiratory response to CO_2 inhalation to reach a new steady state, and the data were collected in the succeeding 5 minutes. The subject was allowed a brief respite (4 to 5 minutes) after each exposure to a CO_2 mixture and a 10-minute rest midway in the series of eight runs comprising the duplicate determination of CO_2-ventilatory response.

After correction of the measured expired air volume to standard conditions, respiratory 1-minute volume, tidal volume, and respiratory frequency were calculated as averages for the 5-minute periods of data measurement. The average end-tidal CO_2 tension was obtained by planimetry from the strip chart recording, and a correction was made for dead-space error as previously determined at the Institute for Environmental Medicine† to obtain the values for alveolar pCO_2 needed in plotting the alveolar pCO_2-ventilation response curves.

A3.5.2.3 Results and Discussion

Mean values for duplicate measurements of end-tidal CO_2 tension, respiratory 1-minute volume, tidal volume, and respiratory frequency for individual subjects are given in Table A32. Individual graphs for respiratory parameters plotted against CO_2 tension for pre- and postexposure measurements are shown in Figs. A41, A42, and A43.

Comparison of postexposure data with control data reveals that three subjects (aquanauts 1, 3, and 4) showed a tendency toward an increase in respiratory reactivity to CO_2 at higher levels, as reflected by respiratory rate and 1-minute volume. The remaining subject (aquanaut 2), however, displayed a tendency toward a reduction in reactivity.

---

*C. J. Lambertsen and J. M. Benjamin, Jr., "Breath-by-Breath Sampling of End-Expiratory Gas," J. Appl. Physiol. 14, 711-716 (1959).

†C. J. Lambertsen, "The Atmosphere and Gas Exchanges With the Lungs and Blood," p. 639, Fig. 36-6, in "Medical Physiology," V. B. Mountcastle, editor, St. Louis, Mosby, 1968.

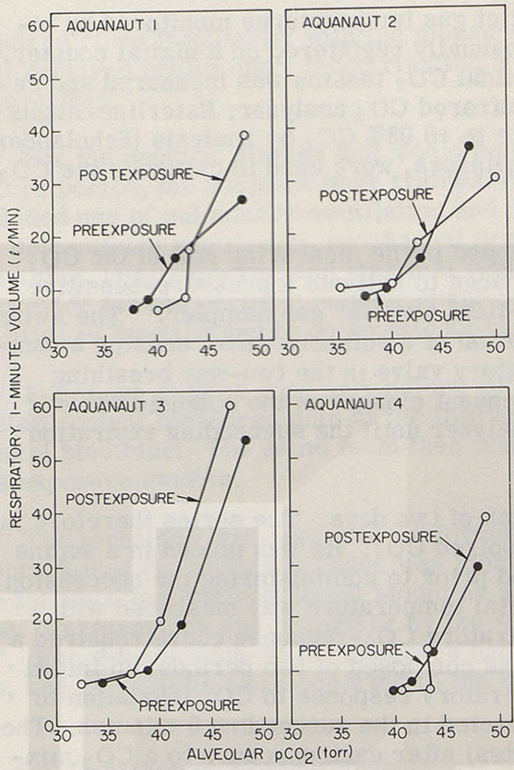


Fig. A41 - Response of the respiratory 1-minute volume to changes in alveolar pCO_2

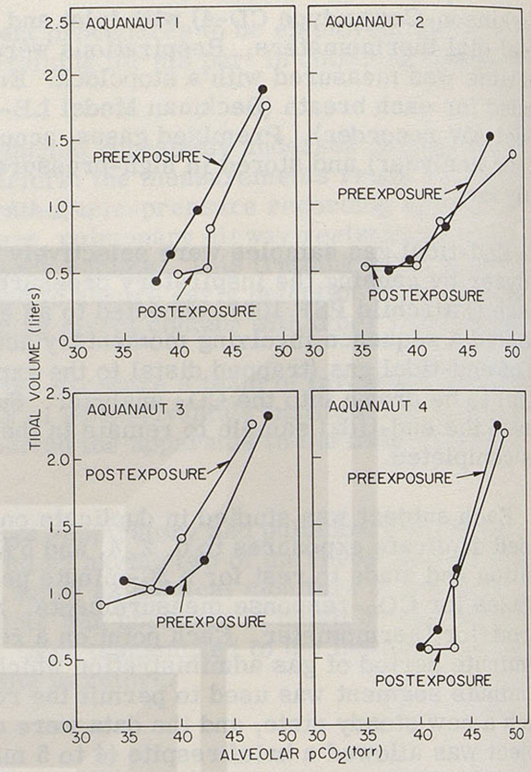


Fig. A42 - Response of the tidal volume to changes in alveolar pCO_2

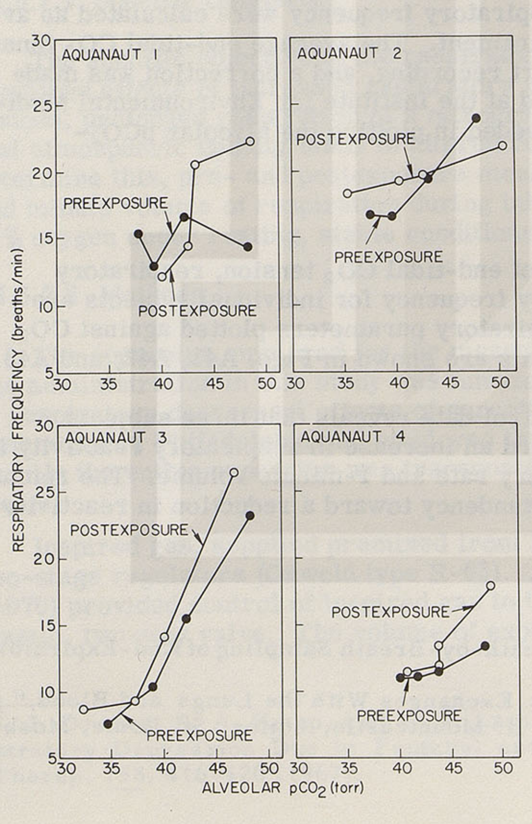


Fig. A43 - Response of the respiratory frequency to changes in alveolar pCO_2

Table A32
Respiratory Response to Changes in Alveolar pCO_2
Before and After the 2-Month Saturation Dive

Aquanaut	Inspired CO_2 (%)	pCO_2 (torr)	Respiratory 1-Minute Volume (1/min)	Tidal Volume (l)	Respiratory Frequency (breaths/min)
Preexposure					
2	0	37.4	8.39	0.504	16.7
	2	39.5	9.64	0.582	16.6
	4	42.8	15.26	0.832	18.4
	6	47.6	36.32	1.521	23.9
3	0	34.6	8.16	1.096	7.6
	2	38.9	10.38	1.011	10.4
	4	42.2	18.75	1.216	15.4
	6	48.4	53.24	2.308	23.2
4	0	40.0	6.12	0.560	11.0
	2	41.7	7.70	0.694	11.1
	4	43.7	13.12	1.160	11.4
	6	48.2	29.30	2.218	13.2
1	0	37.8	6.52	0.438	15.3
	2	39.2	8.22	0.639	12.8
	4	41.8	15.98	0.974	16.6
	6	48.2	26.93	1.884	14.3
Postexposure					
2	0	35.3	9.95	0.544	18.3
	2	40.2	10.51	0.538	19.6
	4	42.5	18.13	0.874	20.7
	6	50.1	30.37	1.395	21.8
3	0	32.4	7.70	0.899	8.6
	2	37.3	9.50	1.017	9.3
	4	40.2	19.56	1.396	14.1
	6	46.9	59.29	2.243	26.4
4	0	40.8	6.39	0.554	11.4
	2	43.4	6.55	0.562	11.8
	4	43.2	14.04	1.052	13.4
	6	48.9	38.54	2.177	17.7
1	0	40.1	5.98	0.493	12.1
	2	42.8	8.22	0.536	14.4
	4	43.2	17.18	0.838	20.5
	6	48.5	38.77	1.748	22.2

Since only four subjects were studied, it was known that even if gross changes in respiratory reactivity occurred, the observations would have to be extended in additional subjects to determine statistical significance. Since no evident gross trend occurred in these four subjects, it can be predicted that demonstration of any obscure effect of this relatively small increase in ambient pressure would require a number of subjects several times larger than the group studied. Moreover, any effect thus uncovered would be too small to have practical significance in diving safety. However, it should also be considered that, as depth of chronic exposure is increased to the point of severe respiratory work and narcosis, it is inevitable that changes in respiratory reactivity and regulation will occur.

A3.5.2.4 Conclusions

In conclusion, chronic exposure to a high-nitrogen, normal-oxygen mixture with a density approximately 2 times that of air at sea level induces no detectable increase or decrease in reactivity to the respiratory stimulus, carbon dioxide. It remains likely that exposure to higher densities and nitrogen pressures will induce practically important alterations of respiratory control.

A3.5.3 Diffusion Capacity of the Pulmonary Membrane
R. W. Hyde, A. B. Fisher, and A. B. DuBois, Institute for Environmental Medicine, University of Pennsylvania

A3.5.3.1 Specific Objective

The specific objective of studying the diffusion capacity of the pulmonary membranes was to determine whether prolonged exposure to increased nitrogen pressure and increased gas density affects the alveolar pulmonary capillary membrane and transmembranal diffusion of gases.

A3.5.3.2 Methods

Measurements included pulmonary diffusing capacity, determined by the single-breath carbon monoxide method,* and functional residual capacity, determined by closed-circuit helium equilibration.† From the primary measurements it is possible to calculate the total lung capacity, the mixing efficiency of the gas-containing pulmonary compartment, and the occurrence of any diffusion limitation in the passage of oxygen from alveoli to the pulmonary capillary blood.

Measurements were performed in duplicate during the preexposure control week and repeated in duplicate within 2 days after ascent during the postexposure measurement period at the diving site. No attempt was made to perform the determinations during the high-pressure exposure, since it was judged that the pulmonary membrane characteristics were not likely to change as a physiological limitation.

*C. M. Ogilvie, R. E. Forster, W. S. Blakemore, and T. W. Morton, "A Standardized Breath-Holding Technique for the Clinical Measurement of the Diffusing Capacity of the Lung for Carbon Monoxide," J. Clin. Invest. 36, 1-17 (1957).

†C. D. Needham, M. C. Rogan, and I. McDonald, "Normal Standards for Lung Volumes, Intrapulmonary Gas Mixing and Maximum Breathing Capacity," Thorax 9, 313-325 (1954).

A3.5.3.3 Results and Discussion

Table A33 summarizes the actual determinations made in this phase of the study. None of the parameters studied appeared to have been detrimentally or even detectably affected by the 2-month undersea exposure.

Table A33
Pulmonary Diffusion Measured Before and After the 2-Month Saturation Dive

Aquanaut	Pulmonary Diffusing Capacity (ml/min/torr)		Total Lung Capacity (l)		Mixing Efficiency (%)	
	Predive*	Postdive†	Predive	Postdive	Predive	Postdive
2	30	29	7.9	7.8	87	93
3	36	35	8.3	8.7	89	100
4	27	32	7.5	8.3	93	89
1	28	35	6.3	7.1	90	93
Mean	30	33	7.5	8.0	90	94

*Measurements made 1 month prior to the start of the exposure.
†Measurements made 1 day after the end of the exposure.

With the nearly identical values found in control and postexposure periods, additional studies under the same conditions using many more subjects would be unlikely to show statistically significant changes. On this basis, and because there is no positive indication that membrane characteristics would change due to high nitrogen pressure or due to the increase in gas density associated with residence at an ambient pressure of about 2 atmospheres absolute, it is not considered that extension of this study is needed.

A3.5.3.4 Conclusion

In conclusion, the capacity for exchange of gas by diffusion across the pulmonary capillary membrane is not detectably modified by the chronic exposure to high nitrogen pressure or the increased density of the respired gas.

A3.5.4 Pulmonary Mechanics

A. B. DuBois, A. B. Fisher, C. J. Knight, and C. J. Lambertsen,
Institute for Environmental Medicine, University of Pennsylvania

A3.5.4.1 Specific Objectives

The specific objectives of studying pulmonary mechanics were to determine whether prolonged, continuous respiration of gas of increased density will result in functionally important alterations of the pulmonary mechanics through changes in pulmonary compliance or airway resistance and to determine whether, during the exposure, adaptations to increased gas density will restore respiratory resistance toward normal.

A3.5.4.2 Methods

Airway resistance was determined by simultaneously and continuously measuring transpulmonary pressure and ventilatory flow. From measurements of the change in transpulmonary pressure required to produce a change in lung volume, lung compliance could be calculated. Transpulmonary pressure during spontaneous respiration was measured with a differential pressure transducer (Statham P23-2D-300) connected to a thin-walled, 10-cm-long latex balloon containing 0.2 to 0.5 ml of air and positioned in the esophagus 10 cm cephalad (i.e., upward) from the cardioesophageal junction. The reference port of the pressure transducer was connected to the subject's mouthpiece.

Both the transpulmonary pressure and the change in lung volume measured with the Stead-Wells spirometer were recorded on a two-channel direct-writing recorder during normal tidal respiration. Pressure-vs-volume curves were constructed from these data, and total lung resistance and lung compliance were calculated.* In aquanauts 3 and 4 the pulmonary resistance was calculated as the mean of inspiratory and expiratory resistances. However, aquanauts 1 and 2 had a high and variable expiratory resistance, and in these subjects the pulmonary resistance was calculated during inspiration only. The esophageal pressure at full lung inflation was also recorded.

A3.5.4.3 Results and Discussion

No definite trend was observed in the lung compliance (Table A34 and Fig. A44). Since the preceding phase of the study indicated no significant change in the mean pulmonary diffusing capacity (section A3.5.3.4), there was no evidence that elevated nitrogen pressure or resistance to breathing, alone or together, had deleterious effects on the lungs or led to adaptive changes in the lung tissue. A slight trend toward a decrease in pulmonary resistance from the moderately elevated value at the beginning of exposure to increased ambient pressure occurred over the 60-day study period at diving depth (Table A34 and Fig. A45). No evidence of this persisted after return to 1 atmosphere.

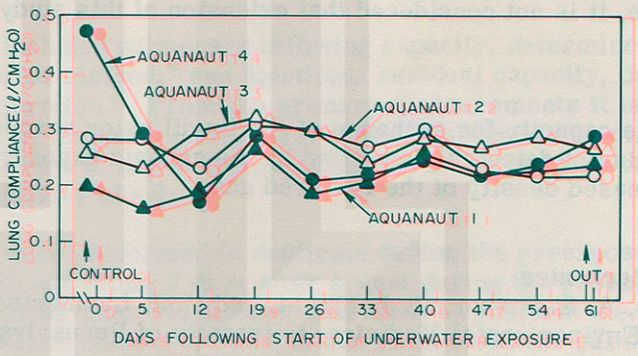


Fig. A44 - Lung compliance during the 60-day saturation dive

---

*R. Marshall, E. H. Lanphier, and A. B. DuBois, "Resistance to Breathing in Normal Subjects During Simulated Dives," J. Appl. Physiol. 9, 5-10 (1956).

Table A34
Pulmonary Compliance and Resistance Before, During, and After the 2-Month Saturation Dive

Day of Dive	Lung Compliance ($l/cm\ H_2O$)					Pulmonary Resistance ($cm\ H_2O/(l/sec)$)				
	Diver 2	Diver 3	Diver 4	Diver 1	Mean	Diver 2	Diver 3	Diver 4	Diver 1	Mean
Predive	0.28	0.26	0.47	0.20	0.30	2.5	1.3	1.6	2.4	2.0
5	0.28	0.23	0.29	0.16	0.24	2.4	3.3	2.4	1.8	2.5
12	0.23	0.30	0.17	0.19	0.22	2.3	2.9	3.0	2.9	2.8
19	0.31	0.32	0.29	0.27	0.30	1.9	2.4	2.7	4.3	2.8
26	0.30	0.30	0.21	0.19	0.25	2.2	1.8	2.0	3.0	2.2
33	0.27	0.24	0.22	0.21	0.24	1.4	3.0	2.0	1.6	2.0
40	0.30	0.29	0.25	0.26	0.28	2.1	2.0	1.6	1.6	1.8
47	0.23	0.27	0.22	0.23	0.24	0.8	1.9	2.1	2.7	1.9
54	0.22	0.29	0.24	0.23	0.24	1.8	2.1	1.2	2.1	1.8
Postdive	0.22	0.27	0.29	0.24	0.26	0.7	2.2	2.6	2.2	1.9

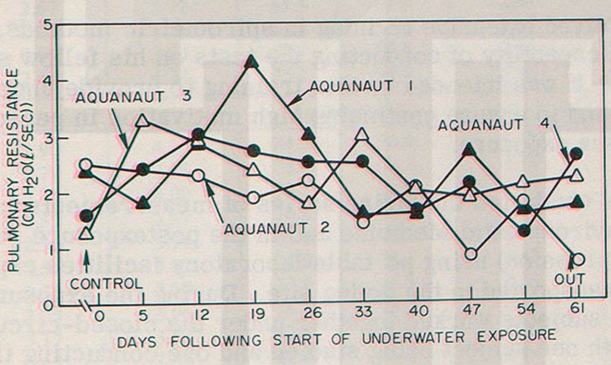


Fig. A45 - Pulmonary resistance during the 60-day saturation dive

The moderate elevation of respiratory resistance due to increased gas density was not expected to produce a major change in the compliance of the lung. The initial and partially sustained increase in pulmonary resistance can be considered as reflecting gas-density effects on airway resistance rather than changes in the lungs or bronchioles themselves. When exposure to increasingly higher atmospheric densities occurs, it is inevitable that sustained increases in airway resistance and work of breathing will induce more gross alterations of the respiratory function.

A3.5.4.4 Conclusion

In conclusion, no effect on pulmonary mechanics was observed that should impose an obstacle to full operational exploitation of undersea activity using nitrogen with a sea-level-equivalent oxygen partial pressure at the depth employed for Tektite I.

A3.5.5 Ventilatory Function

C. J. Knight, C. J. Lambertsen, and A. B. DuBois, Institute for Environmental Medicine, University of Pennsylvania

A3.5.5.1 Specific Objective

The specific objective of studying the ventilatory function was to determine whether continuous prolonged exposure to a respiratory environment of increased density and viscosity, represented by a nitrogen-oxygen mixture at about 2.15 atmospheres absolute, would result in progressive changes in pulmonary ventilatory volume and function. Such changes could result from respiratory exhaustion or from improvement in conditioning of the respiratory muscles.

A3.5.5.2 Methods

An electrically driven Stead-Wells spirometer equipped with a recording drum was employed for preexposure and postexposure examinations, and an identical unit was installed in the habitat for use during the undersea exposure phase. Full study of the pulmonary ventilatory function prior to exposure to increased ambient pressure included measurements of vital capacity, residual volume, maximum voluntary ventilation and maximum expiratory and inspiratory flow rates, intrathoracic pressure, pulmonary airway resistance, work of breathing, and pulmonary compliance.

The subjects received extensive training in spirometric methods, so that each subject had the technical capability of conducting the tests on his fellow subjects during the underwater exposure. It was intended by this training to provide understanding of the nature of these tests and to ensure continuing high motivation in personal performance throughout the undersea exposure.

The investigators conducted the entire series of measurements in the control period at the Institute for Environmental Medicine and in the postexposure period (within the first day after decompression) using portable laboratory facilities especially designed for the purpose and transported to the diving site. During the exposure phase in the undersea habitat, two subjects worked together under the closed-circuit-TV supervision of an investigator, with one subject being studied and one conducting the actual tests.

All measurements were performed before and after the 60-day exposure. In addition certain measurements were obtained at regular weekly intervals during submergence to determine the rate of development of any changes in vital capacity, maximal ventilatory capacity, transpulmonary pressure, flow rate, airway resistance, work of breathing, and pulmonary compliance.

A3.5.5.3 Results and Discussion

The ventilatory function measurements obtained before, during, and after the 60-day exposure are summarized in Table A35 and Figs. A46 through A50.

Preexposure studies of the four subjects confirmed normal pulmonary function in these individuals. On beginning the 2-month underwater period, maximal midexpiratory rates and maximal voluntary ventilation decreased by about 25%. The initial changes are compatible with the effects of an increased airway resistance due to the increased gas density at the depth of the habitat.* These earliest measures after beginning the exposure

---

*A. B. Fisher, A. B. DuBois, R. W. Hyde, C. J. Knight, and C. J. Lambertsen, "Effect of 2 Months' Undersea Exposure to N_2-O at 2.2 atm on Lung Function," J. Appl. Physiol. 28, 70-74 (1970); R. Marshall, E. H. Lanphier, and A. B. DuBois, "Resistance to Breathing in Normal Subjects During Simulated Dives," J. Appl. Physiol. 9, 5-10 (1956).

Table A35
Pulmonary Functions Before, During, and After the 2-Month Saturation Dive

Day of Dive	Vital Capacity (ℓ)	Expiratory Reserve Volume (ℓ)	Inspiratory Capacity (ℓ)	Forced Expired Volume (%/sec)	Forced Expired Volume (%/3 sec)	Maximal Midexpiratory Flow Rate (ℓ/sec)	Maximal Midinspiratory Flow Rate (ℓ/sec)	Maximal Voluntary Ventilation (ℓ/min)
Aquanaut 2								
Predive	5.81	1.53	4.29	87.1	98.4	5.92	7.34	191.8
5	5.62	1.96	3.66	80.0	99.2	4.60	5.63	125.1
12	5.57	1.94	3.63	81.8	99.6	4.62	5.82	146.7
19	5.74	2.10	3.64	81.4	100.0	4.42	6.10	158.4
26	5.50	1.64	3.87	79.8	99.1	4.16	5.98	151.1
33	5.47	1.64	3.84	82.0	100.0	4.20	6.20	154.0
40	5.71	2.18	3.53	82.2	99.4	4.45	5.69	149.0
47	5.63	1.86	3.76	78.9	99.6	4.35	5.90	154.3
54	5.80	1.95	3.86	83.5	99.6	4.86	6.66	172.4
Postdive	5.72	2.02	3.70	82.4	99.1	5.00	10.00	233.0
Aquanaut 3								
Predive	6.18	1.77	4.42	75.7	95.8	3.80	6.65	168.7
5	6.52	1.79	4.73	68.8	96.9	3.05	5.32	104.4
12	6.17	2.14	4.03	69.6	96.4	3.14	4.26	127.4
19	6.21	2.80	3.41	65.1	92.5	2.80	4.54	125.7
26	6.31	1.69	4.63	68.6	93.6	3.10	4.62	122.5
33	6.47	1.67	4.80	67.2	92.7	3.11	4.76	120.2
40	6.44	2.67	3.77	65.5	92.5	2.96	4.78	128.4
47	6.61	2.25	4.36	64.8	93.8	3.13	5.12	119.5
54	6.50	2.66	3.83	57.5	93.6	2.93	4.61	120.5
Postdive	6.82	2.48	4.34	73.2	95.5	3.90	7.09	184.5
Aquanaut 4								
Predive	6.22	1.90	4.33	84.5	96.9	6.52	7.90	175.1
5	6.34	2.79	3.54	73.6	96.3	4.18	6.32	154.9
12	6.52	2.52	4.00	75.7	96.9	4.37	6.70	198.0
19	6.40	2.52	3.87	70.8	96.3	4.18	6.98	181.7
26	6.49	2.50	3.99	69.0	96.5	4.02	6.52	175.8
33	6.42	2.50	3.92	75.0	97.4	4.47	6.27	190.3
40	6.44	2.53	3.90	75.9	96.7	4.50	6.51	187.8
47	6.68	2.73	3.96	76.2	98.4	4.61	7.07	208.3
54	6.70	3.17	3.52	72.6	97.4	4.42	6.92	195.6
Postdive	6.50	2.65	3.85	86.5	99.2	6.04	10.6	260.6
Aquanaut 1								
Predive	4.72	1.64	3.08	76.5	94.3	3.05	7.51	170.8
5	4.56	1.40	3.16	69.8	93.6	2.38	4.82	133.1
12	4.62	1.62	3.01	71.6	95.1	2.40	4.82	133.3
19	4.68	1.90	2.78	70.4	92.9	2.58	5.20	139.1
26	4.67	1.50	3.17	70.4	93.4	2.56	5.97	118.9
33	4.58	1.59	2.99	70.5	91.8	2.60	5.25	123.5
40	4.64	1.54	3.10	71.5	92.7	2.59	5.20	116.3
47	4.74	1.45	3.29	70.2	94.0	2.55	5.57	127.1
54	4.78	1.41	3.37	67.7	90.9	2.32	4.83	130.3
Postdive	4.79	1.49	3.30	73.7	90.3	2.92	7.98	187.4
Mean of the Four Aquanauts								
Predive	5.73	1.71	4.03	81.0	96.4	4.82	7.35	176.6
5	5.76	1.98	3.77	73.0	96.5	3.55	5.52	129.4
12	5.72	2.06	3.67	74.7	97.0	3.63	5.40	151.4
19	5.76	2.33	3.42	71.9	95.4	3.50	5.70	151.2
26	5.74	1.83	3.92	72.0	95.6	3.46	5.77	142.1
33	5.74	1.85	3.89	73.7	95.5	3.60	5.62	147.0
40	5.81	2.23	3.58	73.8	95.3	3.62	5.54	145.4
47	5.92	2.07	3.84	72.5	96.4	3.66	5.91	152.3
54	5.94	2.30	3.64	70.3	95.4	3.63	5.76	154.7
Postdive	5.96	2.16	3.80	79.0	96.0	4.46	8.92	216.4

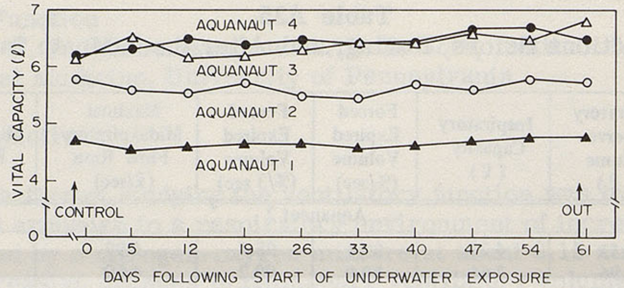


Fig. A46 - Vital capacity during the saturation dive

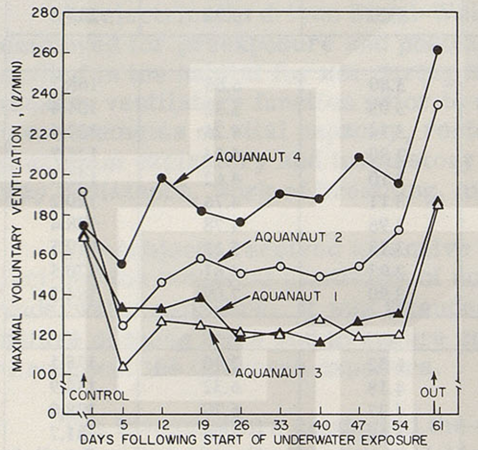


Fig. A47 - Maximum voluntary ventilation during the saturation dive

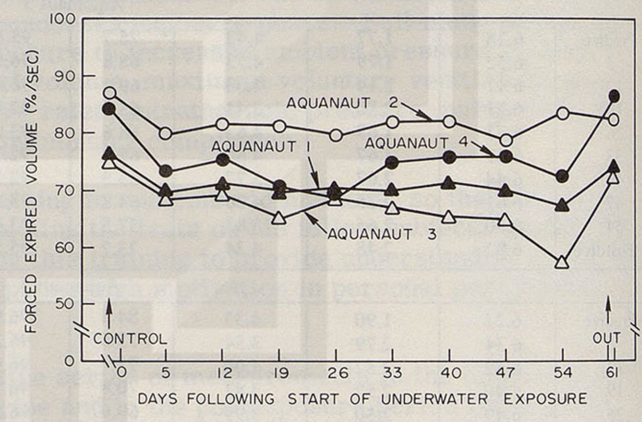


Fig. A48 - Forced expiratory volume during the saturation dive

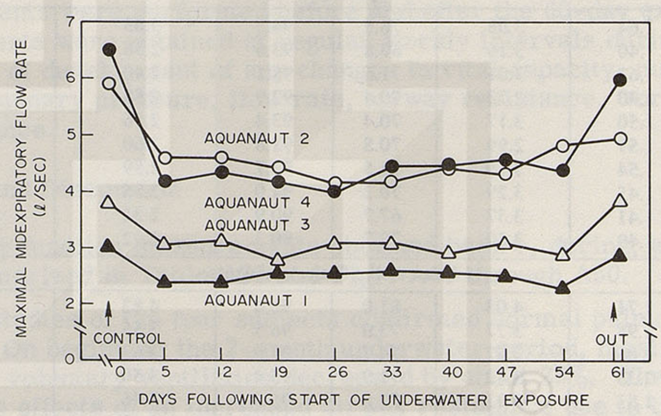


Fig. A49 - Maximal midexpiratory flow rate during the saturation dive

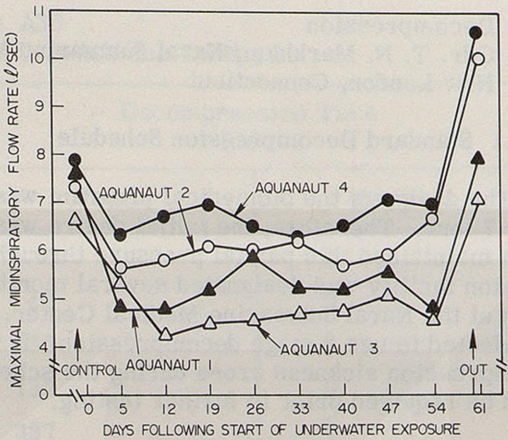


Fig. A50 - Maximal midinspiratory flow rate during the saturation dive

can be considered as controls for the subsequent period of continuous exposure. After the initial effect of entry into the positive pressure environment, maximal voluntary ventilation in two of the subjects increased progressively during the underwater period, suggesting increase in efficiency of the respiratory muscles as a result of physical training.* Vital capacity during this time also showed a slight increase of about 10% in two subjects and remained unchanged in the other two. The small vital-capacity changes are also consistent with the known effects of training and exercise on vital capacity.

Ventilatory-function tests were repeated in the immediate postexposure phase. The results of these measurements are essentially unchanged from those obtained during the control week 4 months previously. The small rise in vital capacity of two subjects and the increase in maximal voluntary ventilation suggested by the measurements obtained during the actual underwater phase were confirmed.

A3.5.5.4 Conclusions

The four aquanauts had normal lungs at the start of the study. During the underwater exposure, resistance to breathing was increased approximately 25%, compatible with increase in gas density. There is a suggestion that physical training, possibly due to the sustained elevation of work of breathing, resulted in improved respiratory muscular performance and increased vital capacity of some subjects. The pulmonary function returned to normal after the exposure.

There was no evidence of deleterious effect upon ventilatory function as a result of a 2-month habitation at 2.15 atmospheres absolute in the nitrogen-oxygen mixture employed.

---

*J. Mead, "Measurement of Inertia of the Lungs at Increased Ambient Pressure," J. Appl. Physiol. 9, 208-212 (1956).

A3.6 Decompression
Cdr. T. N. Markham, Naval Submarine Medical Center, New London, Connecticut

A3.6.1 Standard Decompression Schedule

The design of the biomedical program was based on an oxygen partial pressure of 158 ± 7 torr. Therefore, the initial desire was to develop a decompression schedule which maintained this partial pressure throughout decompression. Further the decompression facility was designated several months after schedule preparation and testing began at the Naval Submarine Medical Center. To accommodate both these restraints it was elected to use a stage decompression. It was also determined that if any cases of decompression sickness arose during the schedule testing, a revision of the schedule would be required prior to further testing.

After the first test, which maintained pO_2 at 158 ± 7 torr during decompression, it became evident such a tight control of oxygen would be very difficult in an operational setting. Therefore the decompression media was changed to air. With this change four more test dives were calculated by the method of Workman* and conducted until the schedule had been extended to 19 hours and 25 minutes of decompression and only one dive free of decompression sickness had been performed. It then appeared necessary to incorporate some oxygen decompression within the schedule to prevent further prolongation. Following the addition of 4 hours and 25 minutes of oxygen breathing to the schedule the two most susceptible subjects were safely decompressed after a 42-foot saturation dive. The final decompression schedule used in Tektite I is seen in Table A36. At the conclusion of Tektite I the four aquanauts were decompressed using this schedule without any development of decompression sickness.

A3.6.2 Emergency Decompression Schedule

Under contract to NASA, J and J Marine Diving Company, Inc., Pasadena, Texas, conducted a series of test dives to determine the safe surface interval between direct surfacing from the 42-foot saturation depth and the onset of decompression sickness. This series of dives resulted in the shortest surface interval being 18 minutes. Therefore a 15-minute safe period was considered possible in which to return a subject to pressure.† During these test dives a decompression schedule was developed which used an overpressure return and early oxygen decompression. This schedule was successful in treating all their cases of decompression sickness and after slight modification was employed as the Tektite I emergency decompression schedule (Table A37).

A3.6.3 Decompression Facilities and Procedures

The decompression complex used in Tektite I was the Advanced Diving System IV (ADS IV) leased from Ocean Systems, Inc. This system consisted of a twin-lock deck decompression chamber (DDC), a submersible decompression chamber (SDC), a control console, an air compressor, an air conditioning unit for the deck chamber, and a bottled oxygen supply. Each lock of the DDC measured 4-1/2 feet in diameter and was 7 feet long. Carbon dioxide was controlled by ventilation with air whenever pCO_2 values approached 4 torr. Oxygen was supplied to the DDC through masks via demand regulators.

*R. D. Workman, "Calculation of Decompression Schedules for Nitrogen-Oxygen and Helium-Oxygen Dives," U.S. Navy Experimental Diving Unit Research Report 6-65, 1965.
†P. O. Edel, "Delineation of Emergency Surface Decompression and Treatment Procedures for Project Tektite Aquanauts," J and J Marine Diving Co., Inc., Pasadena, Apr. 20, 1969.

Table A36
Regular Decompression Schedule for Tektite I

Depth (ft)	Breathing Media	Time at Stop (min)	Decompression Time (min)	
			Total	Oxygen
42	Air	—*	0	0
↓	Air	12†	12	0
30	Air	120	132	0
↓	Air	5	137	0
25	Air	200	337	0
↓	Air	5	342	0
20	Air	170	512	0
20	Oxygen	30	542	30
↓	Oxygen	5	547	35
15	Air	20	567	35
15	Oxygen	30	597	65
15	Air	20	617	65
15	Oxygen	30	647	95
15	Air	20	667	95
15	Oxygen	30	697	125
15	Air	20	717	125
15	Oxygen	30	747	155
↓	Oxygen	5	752	160
10	Air	60	812	160
10	Oxygen	30	842	190
10	Air	20	862	190
10	Oxygen	30	892	220
10	Air	20	912	220
10	Oxygen	40	952	260
↓	Oxygen	5	957	265
5	Air	200	1157	265
↓	Air	5	1162 (19 hr 22 min)	265 (4 hr 25 min)
Surface	Air	—	—	—

*Aquanauts will be transferred via the personnel transfer capsule to the deck decompression chamber and held at a depth of 42 feet until all are transferred and the topside crew is ready for decompression.

†All depth changes during the decompression will be made at a rate of 1 foot per minute. If the depth changes occur slower, the time will be added to the total decompression time.

Table A37
Emergency Recompression and Decompression Following an Explosive Decompression (Inadvertent Surfacing)

Depth (ft)	Breathing Media	Time at Stop (min)	Decompression Time (min) Total	Oxygen
60*	Oxygen	20	20	20
↓	Oxygen	5	25	25
55	Air	20	45	25
↓	Air	5	50	25
50	Oxygen	20	70	45
↓	Oxygen	5	75	50
45	Air	20	95	50
↓	Air	5	100	50
40	Oxygen	20	120	70
↓	Air	15	135	70
25	Air	60	195	70
↓	Air	5	200	70
20	Air	90	290	70
20	Oxygen	30	320	100
↓	Oxygen	5	325	105
15	Air	90	415	105
15	Oxygen	60	475	165
↓	Air	5	480	165
10	Air	120	600	165
10	Oxygen	60	660	225
↓	Oxygen	5	665	230
5	Air	150	815	230
5	Oxygen	60	875	290
↓	Air	5	880 (14 hr 40 min)	290 (4 hr 50 min)
Surface	Air	—	—	—

*An overpressure is applied on recompression when an aquanaut inadvertently surfaces.

There were two masks in each compartment. Each lock of the DDC and the SDC contained communication with the control console. All gas supplied to or exhausted from either the DDC or SDC was controlled at the console. The entire system could be pressurized to an equivalent depth of 600 feet of sea water and was provided with mixed-gas diving capability, although mixed gas was not available during Tektite I.

During the daily operation the decompression complex was under the direct supervision of the senior enlisted diver on watch and manned by either another diver or an Ocean Systems representative. The crane was manned at all times in the event an emergency habitat evacuation was required. Further daily drills were conducted by each watch section exercising the decompression complex, the crane, or the small boats used for surface support in the event of an inadvertent aquanaut surfacing.

A3.6.4 Excursion Diving Decompression Schedules

Due to the nitrogen/oxygen mixture used in the habitat (pO_2 158 ± 7 torr), the saturation depth of Tektite I was an air equivalent depth of 49 feet. Therefore the vertical excursions on air scuba were calculated from that depth. This allowed a shallower excursion of approximately 30 feet without decompression.* This upper limit was set at a depth of 20 feet of sea water. Excursions shallower than this were not allowed due to the hazard of decompression sickness and the possibility of inadvertent surfacing.

No-decompression and decompression schedules were established for deeper excursions by modifying the U.S. Navy Standard Air Table 1-6, "No decompression" limits and repetitive group designation table for "no decompression" dives, and Table 1-5, U.S. Navy Standard Air Decompression Table (Tables A38 through A41).† The modifications were made in a conservative direction. These tables are used in accordance with directions given in the U.S. Navy Diving Manual for Table 1-5, 1-6, 1-7, and 1-8 with the exception that the surface interval noted in Table 1-7 is considered the interval taken in the habitat. Further, when following a deep excursion by a shallow excursion (i.e., above the 42-foot saturation depth) the diver must have been in repetitive group E or lower to go to 30 feet of sea water and in group B or lower to go to 20 feet of sea water depth. The aquanauts attempted to plan their daily diving schedules in order to make any anticipated shallow excursions prior to deep excursion. During the entire operation it was never necessary for aquanauts to make decompression dives to return to the habitat from depth. There were no cases of decompression sickness occurring under pressure during the saturation phase of Tektite I.

A3.6.5 Summary of Decompression

Although the decompression schedule preparation for Tektite I was prepared for an operational program, it became evident during its preparation that the controlling tissue for nitrogen saturation decompression is far beyond the 240-minute level suggested by Workman. The data collected during this series of dives supports the much longer controlling tissue described by Buhlmann et al.‡ The schedule prepared and used for Tektite I is not an optimum schedule but does appear safe from an air saturation depth equivalent to 49 feet of sea water.

*R. D. Workman, "Calculation of Decompression Schedules for Nitrogen-Oxygen and Helium-Oxygen Dives," U.S. Navy Experimental Diving Unit Research Report 6-65, 1965.
†"U.S. Navy Diving Manual, General Principles of Diving," NavShips 250-538, Navy Department, Washington, U.S. Government Printing Office, 1963.
‡A. A. Buhlmann, P. Frei, and N. Keller, "Saturation and Desaturation with N_2 and He at 4 Atmospheres," J. Appl. Physiol. 23, 458-462 (1967).

Table A38
No-Decompression Limits and Repetitive Group Designations for Aquanaut Vertical Excursions (Downward) From a Saturated Depth of 42 Feet

Depth From Surface (ft)	Limit of Time at Depth (min)	Repetitive Group														
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
60	300	60	120	200	300	—	—	—	—	—	—	—	—	—	—	–
65	300	30	60	100	150	200	300	—	—	—	—	—	—	—	—	–
70	300	20	40	60	90	120	150	200	300	—	—	—	—	—	—	–
75	300	15	30	40	60	90	110	145	180	200	300	—	—	—	—	–
80	300	10	20	30	50	60	80	100	120	150	180	200	300	—	—	–
85	300	5	10	20	30	40	50	70	90	100	120	140	180	200	240	300
90	180	5	10	20	25	30	40	50	70	90	100	110	130	150	180	–
100	90	—	5	10	20	25	30	40	50	60	70	80	90	—	—	–
120	40	—	—	5	10	15	20	25	30	35	40	—	—	—	—	–
140	25	—	—	—	5	10	15	20	25	—	—	—	—	—	—	–
160	10	—	—	—	—	—	5	10	—	—	—	—	—	—	—	–

Table A39
Standard Decompression for Aquanauts Exceeding the No-Decompression Limits of Table A38

Depth (ft)	Bottom Time (min)	Time to First Decompression Stop (min)	Time at Stop (min)			Total Decompression Time (min)	Repetitive Group at End of Decompression
			80 ft	70 ft	60 ft		
90	200	1	—	—	2	3	N
	220	1	—	—	7	8	N
	240	1	—	—	11	12	O
	260	1	—	—	15	16	O
100	100	1	—	—	3	4	L
	120	1	—	—	7	8	M
	140	1	—	—	12	13	M
	160	1	—	—	25	26	N
	180	1	—	—	35	36	O
	200	1	—	—	40	41	O
120	50	1	—	—	8	9	K
	60	1	—	—	14	15	L
	80	1	—	—	24	25	N
	100	1	—	2	41	44	O
	120	1	—	6	52	59	O
	150	1	—	13	72	86	Z
140	30	2	—	—	7	9	J
	40	2	—	—	18	20	L
	60	2	—	10	30	42	N
	80	2	—	20	50	72	O
160	20	2	—	—	5	7	H
	40	2	—	10	30	42	M
	60	2	1	25	50	78	O

Table A40
Change of the Repetitive Group as a function of the Time Interval at the 42-Foot Saturation Depth

Repetitive Group at Beginning of the Interval	Repetitive Group at the End of the Interval															
	Z	O	N	M	L	K	J	I	H	G	F	E	D	C	B	A
Z	0:22	0:34	0:48	1:02	1:18	1:36	1:55	2:17	2:42	3:10	3:45	4:29	5:27	6:56	10:05	12:00
O	—	0:23	0:36	0:51	1:07	1:24	1:43	2:04	2:29	2:59	3:33	4:17	5:16	6:44	9:54	12:00
N	—	—	0:24	0:39	0:54	1:11	1:30	1:53	2:18	2:47	3:22	4:04	5:03	6:32	9:43	12:00
M	—	—	—	0:25	0:42	0:59	1:18	1:39	2:05	2:34	3:08	3:52	4:49	6:18	9:28	12:00
L	—	—	—	—	0:26	0:45	1:04	1:25	1:49	2:19	2:53	3:36	4:35	6:02	9:12	12:00
K	—	—	—	—	—	0:28	0:49	1:11	1:35	2:03	2:38	3:21	4:19	5:48	8:58	12:00
J	—	—	—	—	—	—	0:31	0:54	1:19	1:47	2:20	3:04	4:02	5:40	8:40	12:00
I	—	—	—	—	—	—	—	0:33	0:59	1:29	2:02	2:44	3:43	5:12	8:21	12:00
H	—	—	—	—	—	—	—	—	0:36	1:06	1:41	2:23	3:20	4:49	7:59	12:00
G	—	—	—	—	—	—	—	—	—	0:40	1:15	1:59	2:58	4:25	7:35	12:00
F	—	—	—	—	—	—	—	—	—	—	0:45	1:29	2:28	3:57	7:07	12:00
E	—	—	—	—	—	—	—	—	—	—	—	0:54	1:57	3:22	6:32	12:00
D	—	—	—	—	—	—	—	—	—	—	—	—	1:09	2:38	5:48	12:00
C	—	—	—	—	—	—	—	—	—	—	—	—	—	1:39	4:49	12:00
B	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2:10	12:00
A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	12:00

Table A41
Repetitive Dive Timetable: Influence of Repetitive Group on the Allowable Time at a Given Depth

Repetitive Group	Repetitive Dive Depth*				
	90 ft	100 ft	120 ft	140 ft	160 ft
A	7	6	4	3	3
B	17	13	9	7	6
C	25	21	15	11	10
D	37	29	20	16	13
E	49	38	26	20	16
F	61	47	31	24	20
G	73	56	37	29	24
H	87	66	43	33	27
I	101	76	50	38	31
J	116	87	57	43	34
K	138	99	64	47	38
L	161	111	72	53	42
M	187	124	80	58	47
N	213	142	77	64	51
O	241	160	96	70	55
Z	257	169	100	73	57

*The numbers in the columns are times in minutes to be deducted from the maximum allowable times at depth.

A3.6.6 Delineation of Emergency Surface Decompression and Treatment Procedures for Project Tektite I Aquanauts

Peter O. Edel, J and J Marine Diving Co., Inc., Pasadena, Texas

A3.6.6.1 Summary

Project Tektite I required that four scientist-aquanauts were to live for 2 months in a habitat at a depth of 43 feet in Lameshur Bay, St. John, Virgin Islands, during which time their breathing mixture was to be 91% N_2, 9% O_2. A series of experiments was therefore conducted to determine to what degree of safety the scientists could make a no-decompression ascent to surface from the habitat and the maximum surface decompression interval they could safely undergo.

From these experiments it was determined that a 15-minute surface interval was safe for six subjects and that one subject developed serious neurocirculatory sumptoms after 19 minutes on the surface.

Recompression-decompression schedules were calculated for treatment of these subjects after their exposure to surface intervals of various lengths of time. All subjects were successfully treated according to these tables. A safe surface interval of 15 minutes and use of the recompression-decompression schedules that were developed as a result of this experimentation are recommended for incorporation into the Project Tektite I operational procedures.

A3.6.6.2 Introduction

Project Tektite I required four scientist/aquanauts to live 60 days in a habitat on the sea floor at a depth of 43 feet. The scientists made frequent excursion dives from the habitat, during the day and at night, to study the flora and the fauna of nearby coral reefs. The excursion dives were made with standard scuba equipment, and two 71-cu-ft scuba bottles provided the air supply. This supply of air permitted the scientists to swim for about 1 to 2 hours at this depth, or to travel about 1000 feet from the habitat before returning to it.

The possibility that equipment failure, injury, or shark attack might force the swimmers to surface had to be anticipated. Since their bodies were saturated with the inert gas of their habitat breathing mixture (91% nitrogen, 9% oxygen) at the habitat pressure of 43 feet of seawater (FSW), ascent to the surface would have constituted an emergency situation requiring immediate pressurization.

To what degree of safety a diver, breathing air at a depth greater than 33 FSW (1 atmosphere), could make a no-decompression ascent to surface when his slowest tissues are totally nitrogen saturated had never been established. Furthermore the length of time that a diver can remain at surface pressure following such an ascent before experiencing the serious effects of decompression sickness had never been determined, and this exposure time was critical to the safety of the Tektite I divers and will continue to be critical in future Tektite dives. There are no valid decompression tables indicating the appropriate procedures to be followed in decompressing a diver from a state of total nitrogen saturation. Neither are there any published tables indicating the appropriate recompression and decompression procedures to be followed in the event of emergency surfacing in the circumstances under which Tektite divers live and work.

A3.6.6.3 Purpose

The present experimentation was conducted (a) to determine the maximum safe surface interval that the Tektite I divers could sustain without developing symptoms of decompression sickness after remaining at a depth of 42 FSW* in a habitat in which they would be totally saturated with a breathing mixture of 160 torr O_2 in nitrogen and (b) to determine safe recompression-decompression schedules that would permit the Tektite I divers to return to their habitat after this maximum safe surface interval, or that would allow their being brought to surface for emergency treatment, if such became necessary.

A3.6.6.4 Method

Six tests were performed involving two subjects each. All of the subjects were divers whose ages varied from 20 to 52 years. The subjects were pressurized in a double-lock pressure chamber that was 4 feet in diameter and 14 feet long, in accordance with the compression-decompression schedules described hereafter. The small chamber limited the movements of the subjects; they were, however, instructed to engage in mild physical activity for 15 minutes prior to any scheduled reduction in pressure.

The partial pressure of carbon dioxide in the chamber atmosphere was maintained between 0.6 and 5 torr during periods of intermittent ventilation (with air) and at less than 4 torr during continuous ventilation. In addition the pressure chamber's content of carbon dioxide was reduced through a more rapid ventilation with air to an even lower level prior to any reduction in pressure. In each test, accuracy was held to within 1/2

*Decompression tables were based on a planned saturation depth of 42 FSW. The actual saturation depth was nominally 43 FSW, but the difference was considered negligible.

foot of the prescribed simulated depth. The 91% nitrogen, 9% oxygen gas mixture used in the final 2 hours of compression at the 42-FSW level was purchased from commercial suppliers and was tested to assure that accuracy was maintained to within 0.1% of the prescribed ratio.

After a change in the partial pressure of nitrogen in a breathing mixture, the change in nitrogen saturation of bodily tissues occurs at an exponential rate that is limited by the slowest tissue's half-saturation time. This half-saturation time, of course, varies greatly among individuals, but the time selected — 360 minutes — is widely accepted in diving practices as accommodating the slowest tissues of the vast majority of the diving population.

Three days at 42 FSW would be required to bring the 360-minute tissues to an almost total state of nitrogen equilibrium with the proposed breathing atmosphere of the Tektite I habitat. Because of the cost of doing so and the discomfort that the divers would have to endure it would have been impractical to saturate the Tektite I divers for such a length of time in a chamber on a breathing mixture of 91% N_2, 9% O_2. A shortened exposure period at greater depth, based upon the following theoretical considerations, was therefore calculated: Breathing air at a pressure of 1 atmosphere (which equals 33 FSW absolute) produces a partial pressure of nitrogen in the tissues equal to that of 26 FSW (absolute) pressure — 79% of the total pressure of 1 atmosphere.

The Project Tektite I breathing atmosphere was to be a mixture of oxygen and nitrogen, the oxygen limited to 7 FSW (160 torr) partial pressure and the nitrogen to a partial pressure of 68 FSW. (The gage pressure of 42 FSW is equal to 75 FSW absolute pressure; i.e., 42 FSW plus 33 FSW (1 atmosphere) equals 75 FSW absolute.) The Tektite I divers were therefore to undergo an increase in nitrogen partial pressure upon changing from breathing air on the surface to breathing the atmosphere in the Tektite habitat — a pressure of 42 FSW (68 FSW minus 26FSW, or 42 FSW).

If the 42-FSW increase in nitrogen partial pressure in the Tektite I breathing atmosphere were doubled, the nitrogen partial pressure in the slowest half-saturation time tissue would, theoretically, be increased to 50% of the 84-FSW change in the atmospheric nitrogen partial pressure during the period that the slowest tissues half-saturate, namely, 360 minutes. Under a pressure of 139 FSW absolute (106 FSW gage pressure) air has a nitrogen partial pressure of 110 FSW. The nitrogen pressure at 110 FSW is 84 FSW over that of air at surface pressure (1 atmosphere); it is twice the difference between the nitrogen partial pressure of air at 1 atmosphere and that of the atmosphere that was planned for the Tektite I habitat. In 6 hours, therefore, it is theoretically possible to bring about total equilibrium between the nitrogen partial pressure in the slowest tissues and that of the Tektite I breathing atmosphere that would be approximated by a diver's breathing the Tektite I atmosphere for 3 days (or more) at 42 FSW.

The tissues with a half-saturation time of less than 360 minutes will attain higher levels of nitrogen tissue tension during the 360-minute pressurization at 106 FSW but will eliminate nitrogen more rapidly when the pressure is decreased. In the present experimentation it was necessary that the nitrogen partial pressure of all the tissues be approximately equal to that in the Tektite I atmosphere (68 FSW); chamber pressure was therefore decreased from 106 FSW to 53 FSW gage after 360 minutes to desaturate the faster half-saturation-time tissues.

Breathing air at 53 FSW produces the same nitrogen partial pressure in the tissues as is produced by breathing a 91% N_2, 9% O_2 mixture at a depth of 42 FSW. The nitrogen partial pressure is equal to the gage depth in the breathing mixture plus the equivalent absolute depth at sea level (33 feet) multiplied by the percentage of nitrogen in the mixture. For the Tektite I atmosphere the equation is as follows:

$$(42\ \text{FSW} + 33\ \text{FSW}) \times 0.91\ N_2 = 68\ \text{FSWA}.$$

Breathing air at 53 FSW nitrogen partial pressure is

$$(53\ \text{FSW} + 33\ \text{FSW}) \times 0.79\ N_2 = 68\ \text{FSW}.$$

As far as the nitrogen partial pressure is concerned, therefore, both conditions are equal.

Calculations indicate that 16 hours at 53 FSW pressure are required so that the tissues with shorter half-saturation times desaturate to approximate the Tektite I tissue nitrogen partial pressure. Some of the slower tissues will have nitrogen partial pressures slightly in excess of the Tektite I habitat's nitrogen content at the end of this time. To prevent any possible contributory effects resulting from the increased partial pressure of oxygen, the final 2 hours prior to testing the surface interval were spent at 42 FSW, during which time the subjects breathed the specified mixture of 91% N_2, 9% O_2.

The following schedule of pressure exposure was used to establish total equilibrium between the nitrogen saturation in the bodily tissues having a half-saturation time of 360 minutes and the nitrogen content of the Project Tektite I breathing atmosphere:

1. Breathing air at 106 FSW for 6 hours.
2. Breathing air at 53 FSW for 16 or 35 hours.
3. Breathing a 91% nitrogen, 9% oxygen mixture at 42 FSW for 2 hours.

The first three tests used a minimum desaturation period of only 16 hours. This period was increased to 35 hours in the last three tests to determine the validity of the shorter desaturation interval. The allowable safe surface interval following the above schedule was determined by decompressing the subjects from 42 FSW to surface pressure in 1 minute and then observing them for periods lasting 10, 15, and 20 minutes.

Following the interval at surface pressure, the subjects were recompressed in accordance with the schedule in Table A42. These decompression schedules were calculated so that the Tektite I scientists could be safely recompressed and decompressed to habitat depth after any emergency exposure that they might be forced to undergo.

Table A42
Surface Decompression Treatment Schedules for Return to Habitat

Schedule	Surface Interval (min)	Decompression Stages					Total Time (min)
		60 ft	55 ft	50 ft	45 ft	40 ft	
A	0–10	–	20 min (O_2)	20 min (air)	20 min (O_2)	–	60
B	10–20	20 min (O_2)	20 min (air)	20 min (O_2)	20 min (air)	20 min (O_2)	100

Safe decompression schedules are also needed so that the scientists could be further decompressed from the habitat depth to surface should emergency medical treatment be required. Two decompression procedures were therefore tested, one using air breathing only, and the other using alternate periods of air and oxygen breathing (Table A43). Four subjects were decompressed according to the air table, and six according to the air-oxygen schedule. A typical dive profile is shown in Fig. A51. The two decompression schedules that were used in these tests are shown in Fig. A52.

Table A43
Decompression Schedules for Return to Surface After Use of Table A42

Schedule	Decompression Stages					Total Time (hr)
	25 ft	20 ft	15 ft	10 ft	5 ft	
Air decompression		2 hr	2 hr	2 hr	3 hr	9
Air-oxygen decompression	1 hr (O_2)	1 hr (air)	1 hr (O_2)	1 hr (air)	1 hr (O_2)	5

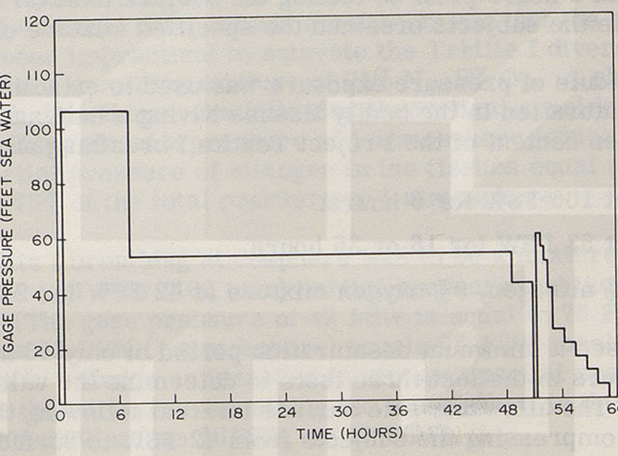


Fig. A51 - Test profile for Tektite I with approximately 35 hours at 53 FSW

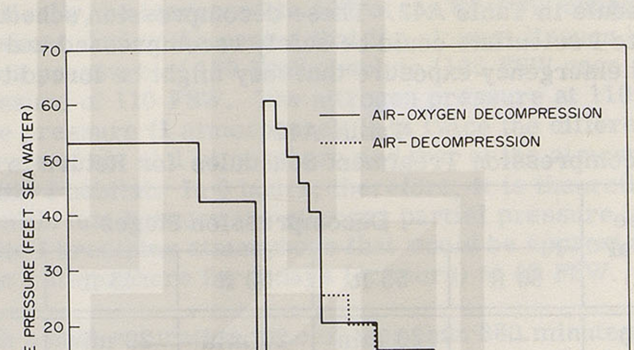


Fig. A52 - Treatment and decompression schedules after surfacing from total saturation at 42 FSW

An additional test, involving two Navy subjects, was carried out to compare the efficacy of the emergency decompression schedules proposed herein with that of the regular decompression schedule adopted for use in the Tektite I Program (Fig. A53 and Table A36).

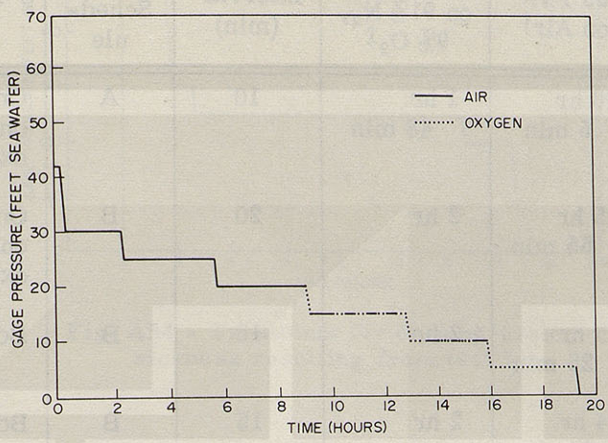


Fig. A53 - Regular decompression schedule for Tektite I

A3.6.6.5 Results

A schedule of the test procedures is shown in Table A44. One of the two subjects exposed to the 10-minute simulated surface interval noticed a very mild pain (grade 1) in his right shoulder. Complete relief was obtained upon recompression to a simulated depth of 55 FSW. The other subject remained symptom-free. There were no symptoms reported by the six subjects who were exposed to the 15-minute surface interval.

Of the two subjects exposed to the 20-minute surface interval, one subject remained symptom-free. The other subject experienced marked neurocirculatory symptoms in the 19th minute of his surface interval. He was immediately recompressed and reported complete relief of symptoms upon arrival at a recompression depth of 60 FSW.

Two Navy volunteer subjects, both qualified divers, were compressed in accordance with the previously tested nitrogen saturation schedule and were then decompressed on the prolonged air-oxygen schedule (Fig. A53 and Table A36). One of the two subjects suffered grade 1 bends in the right ankle upon surfacing. The symptom disappeared without treatment after 4 hours of breathing air at surface pressure.

The tables used to recompress the subjects from surface pressure to 55 or 60 FSW and then to decompress them to the simulated habitat pressure (42 FSW) were apparently safe and effective in the treatment of the two cases (out of 10 subjects) of decompression sickness that occurred during the surface interval. No incidence of decompression sickness occurred during the phase in which the subjects were returned to simulated habitat pressure.

None of the four subjects who were decompressed from 42 FSW on the air decompression table (Table A43) experienced decompression sickness. However, of the six subjects decompressed from 42 FSW on the air-oxygen decompression schedule, one subject suffered very mild (grade 1) bends pain in his right ankle upon surfacing. This

Table A44
Test Profiles

Test No.	Time at 106 FSW on Air* (hr)	Time at 53 FSW on Air†	Time at 42 FSW on 91% N_2, 9% O_2‡	Surface Interval§ (min)	Treatment Schedule	Individual Decompression Schedules
1	6	16 hr 5 min	1 hr 48 min	10	A	One diver on air; one diver on air-oxygen
2	6	15 hr 55 min	2 hr	20	B	One diver on air; one diver on air-oxygen
3	6	35 hr 25 min	2 hr	15	B	Both divers on air
4	6	34 hr 25 min	2 hr	15	B	Both divers on air-oxygen
5	6	35 hr 24 min	2 hr	15	B	Both divers on air-oxygen
6	6	35 hr 23 min	2 hr	None		Decompressed on schedule in Table A36

*Compression to 106 feet: 2 minutes.
†Ascent from 106 feet to 53 feet: 5 minutes.
‡Ascent from 53 feet to 42 feet: 2 minutes.
§Ascent from 42 feet to surface: 2 minutes.

symptom persisted and eventually involved the subject's right knee as well, requiring compression to 60 FSW and treatment according to the modification of Table 6 of the U.S. Navy Diving Manual shown in Fig. A54. This subject has an old injury to the ankle and suffered similar bends symptoms when he was decompressed according to the standard Project Tektite I decompression schedule (test 6, Table A44). He had also suffered previous attacks of bends in this ankle. Shortly after his arrival at 30 FSW the subject complained of "soreness in his chest" and mild substernal distress when he breathed, which were interpreted as being caused by oxygen toxicity. He was then brought to 25 FSW and remained at that pressure breathing air overnight, or 10 hours. In the morning he was brought to 20 FSW, where he remained for 50 minutes breathing air. He was given oxygen for 60 minutes at the 20-FSW depth and remained on oxygen during his 20-minute ascent to surface.

A3.6.6.6 Discussion

The test results indicate that after total saturation at 42 FSW with the proposed Tektite I breathing mixture of 91% N_2, 9% O_2, a surface interval lasting no longer than 15 minutes is reasonably safe against an attack of decompression sickness. One subject in the present investigation experienced serious symptoms of decompression sickness 19 minutes after being brought to surface following the experimental saturation exposure. His symptoms might well have proved fatal had not immediate recompression been possible. A 20-minute surface interval therefore appears to be unsafe. The possibility that

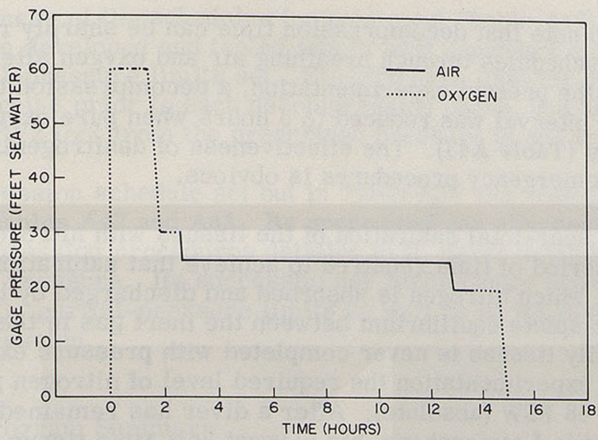


Fig. A54 - Treatment for decompression sickness resulting from test 5

decompression sickness will occur in some subjects during a 15-minute surface interval following saturation with the Tektite I habitat atmosphere cannot be ruled out, since only six tests were made in the present experimentation using the same decompression schedules as used in Project Tektite I.

Although symptoms did not manifest themselves in the other subjects who were exposed to the 15- and 20-minute intervals, there was undoubtedly bubble formation in their tissues which, had the surface interval been extended, would eventually have caused decompression sickness. When tissues are supersaturated with inert gas, the stage is set for an attack of decompression sickness should any further reduction in pressure occur. If supersaturation is great enough, the solution of the gas in the tissues becomes unstable, resulting in a separation into gas and liquid phases. The bubbles thus formed continue growing and create sufficient pressure to cause tissue damage or symptoms of decompression sickness or both.

Once a critical reduction in ambient pressure has taken place, it is only a matter of time before symptoms of decompression sickness become manifest. It must therefore be assumed that some degree of bubble growth would have occurred during the surface interval following any emergency ascent from the Tektite I habitat, whether or not the subject experienced any symptoms of it. The air-oxygen treatment tables shown in Table A42 were calculated to dissolve this bubble formation during decompression to habitat pressure.

By means of a further pressure reduction, according to the schedule shown in Fig. A53, from the equivalent of habitat to surface pressure, the effectiveness of the treatment schedule outlined in Table A43 was tested. Any nitrogen bubbles that form during a surface interval, even symptomatic ones, that are not dissolved through treatment can be expected to become aggravated by further pressure reduction. During decompression or following a diver's return to sea-level pressure, symptoms of previous silent bubble formation may become evident, or symptoms that had disappeared may reassert themselves.

One case of decompression sickness occurred during testing of the standard decompression schedule and one also during the testing of the emergency decompression schedule for Tektite I. As previously noted both instances involved the same individual, who is believed to be unusually susceptible to decompression sickness in this type of pressure exposure. All the other test subjects were able to tolerate the programmed decompression schedules without difficulty.

It is interesting to note that decompression time can be sharply reduced in emergency decompression schedules through breathing air and oxygen alternatively. When air alone was breathed in the present experimentation, a decompression time of 9 hours was required, whereas the interval was reduced to 5 hours when pure oxygen and air were breathed intermittently (Table A43). The effectiveness of denitrogenization via oxygen breathing in Tektite I emergency procedures is obvious.

In tests requiring near-total saturation of the tissues with nitrogen a major difficulty lies in the prolonged period of time required to achieve that saturation level. Because of the exponential rate at which nitrogen is absorbed and discharged by bodily tissues the process of attaining complete equilibrium between the inert gas in the inspired breathing medium and in the bodily tissues is never completed with pressure exposure at a single level. In the Tektite I experimentation the required level of nitrogen partial pressure in the bodily tissues was 68 FSW (absolute). After a diver has remained three days at 42 FSW breathing the Tektite I atmosphere, his slowest half-time tissue (360 minutes) will theoretically attain a nitrogen partial pressure of 67 to 68 FSW (absolute).

The method used in the present investigation to produce maximum nitrogen partial pressure in the slowest tissue — i.e., doubling the nitrogen partial gradient of the breathing atmosphere — was apparently effective. After a diver spends 16 hours breathing air at 53 FSW, his slower tissues — those having a faster half-saturation time than do the 360-minute tissues — has a nitrogen partial pressure of 68 to 69 FSW. This small excess in nitrogen partial pressure over the Tektite I nitrogen pressure would have, at most, a very slight effect on the required Tektite I decompression, and if anything would impose a slightly more rigid test of the decompression table to be followed.

There was no significant difference between the test results involving 16 hours of desaturation at 53 FSW and those involving 35 hours of desaturation at 53 FSW. Extending the period of time spent at 53FSW from 16 to 35 hours reduces the nitrogen partial pressure in the slower tissues so negligibly that the extension of time beyond 16 hours cannot be considered significant in the results of any decompression schedule used.

A3.6.6.7 Conclusions and Recommendations

The following conclusions and recommendations were made for Project Tektite I on the basis of the preceding experimentation.

- In the event that Project Tektite I aquanauts make a planned or accidental ascent to surface after maximum nitrogen saturation at 42 FSW, a surface interval not to exceed 15 minutes is considered safe. This surface interval is recommended for use in formulating Project Tektite I emergency procedures.

- The emergency recompression and decompression schedules shown in Tables A42 and A43 were proven effective and are suggested for use in treatment of Tektite I aquanauts after emergency surfacing. It is also recommended that these schedules be used to return Tektite I divers to their habitat or to the surface under nonemergency circumstances.

- The decompression schedule formulated for the standard (as opposed to emergency) decompression of Project Tektite I divers at the end of their 60-day submergence was found to be satisfactory. Its use is therefore recommended.

- Doubling the nitrogen partial pressure gradient for a period of time equal to that of the half-saturation time of the slowest tissue demonstrated empirically that a desired tissue tension can be reached by the end of that time period. The use of this technique is recommended in experimentation involving total saturation of the tissues with nitrogen or other inert gases.

- The effectiveness of the schedules for treatment (Table A42) and decompression (Table A43) that were developed and tested was in part dependent on adherence to the established CO_2 partial-pressure limits set. Effectiveness likewise depended on the subjects doing mild exercise prior to each decompression phase, and also on the subjects not deviating more than 1/2 foot from the prescribed pressure at any time.

- The decompression schedule set out in Table A36 was tested under the same conditions as those in Tables A42 and A43. Its successful use also depends on the divers following the decompression procedures detailed in it, never deviating more than 1/2 foot from the prescribed pressure. Its successful use furthermore depends on the divers staying within the CO_2 partial-pressure limits as well as on the divers doing mild exercise during decompression.

A3.7 Biomedical Program Summary

C. J. Lambertsen, Institute for Environmental Medicine, University of Pennsylvania, Philadelphia, Pennsylvania, and S. Kronheim, Physiology Branch, Office of Naval Research, Washington, D.C.

The composite of successfully concluded special clinical, physiological, hematological, and microbiological studies is considered to represent the pattern of study required for selection and monitoring in any comparable exploration of unusual chronic exposure to altered gaseous environment. By holding oxygen pressure at normal levels it was possible to prevent all forms of oxygen toxicity. Since no practically important deviations from normal were detected during the prolonged but rather shallow exposure, it can be considered that neither the high nitrogen pressure nor the increased gas density presented important stresses. It should therefore be possible to proceed with free employment of saturation diving under the conditions of Tektite I for operational purposes. However, while the exposure itself induced no detrimental changes, the occurrence of what appeared to be a bubble in the lens of one subject requires careful reappraisal of the decompression requirements for ascent after nitrogen or other saturation diving.

It should be considered inevitable that, as deeper diving with nitrogen-oxygen mixtures is carried out, there will be progressive further increases in respiratory airway resistance, increases in work of breathing, and also progressive increase in the degree of nitrogen narcosis. These all will reduce exercise tolerance, performance, judgment, and the safety of diving operations. At elevated density and nitrogen partial pressure of the gas breathed, the tolerable duration of exposure must be expected to become shorter. Also to be anticipated is the likelihood of a composite of adaptative, compensatory and decompensatory effects, none of which can be clearly predicted in quantitative terms in advance of detailed and comprehensive laboratory experimentation.

A related pattern of conclusions can be derived from dermatological and microbiological observations. While the skin, as a barrier between external and internal environment, was generally unaffected by the clean, usually dry, and only intermittently aqueous overall exposure involved in Tektite I, the skin lining the external auditory canal promptly became infected in each subject. This, actually representing a dermatological rather than an auditory problem, illustrated the natural and well-known consequence of continued wetness of skin difficult to keep clean and free of organic debris. It should be expected that, under conditions of even intermittent diving, similar infections of the skin lining the auditory canal will occur unless scrupulous cleanliness and drying, with avoidance of trauma and crossinfection, are practiced. This circumstance of exceptional susceptibility to infection of the skin of the auditory canal is independent of depth but more likely to be prominent in warmer than in colder environments. It should also be considered that, in future circumstances where cleanliness and drying of skin and clothing are not practiced, where water is contaminated, and where ambient temperature is high enough to maintain high moisture content of skin, general dermatological breakdown and infection can be expected to be a frequent and severe potential complication of prolonged undersea operations.

A4 DATA MANAGEMENT AND THE DIGITAL DATA BANK

A4.1 Introduction

Nicholas Zill, Bellcomm, Inc., Washington, D.C.

A4.1.1 The Data Bank Concept

In an operation of the scope of Tektite I it seemed desirable to have a facility available which could function as a central repository for data generated by the various scientific and engineering components of the operation. Such a facility could serve a number of useful functions, such as (a) organizing the data for rapid access and analysis at the end of the mission, (b) reducing redundant collection of data of common interest to a number of investigators, (c) providing for collection of secondary or background data which individual investigators would not collect, (d) providing feedback during the mission of quick-look analyses of key data for investigators and mission management, (e) encouraging and simplifying the process of correlating data from different investigators, and (f) providing a base for a systems-analysis overview of the operation for planning of and comparison with similar operations in the future.

Naturally, such a facility had to be computer-based for real effectiveness in dealing with the quantity of digital data anticipated. Although the term "data bank" is usually reserved for much larger collections of data than here discussed, the term seemed appropriate for two reasons. First, like other data banks the facility was to have overall cognizance of collection procedures as well as serving as a repository. Second, it was hoped that the Tektite I effort would stimulate the development of much larger and more sophisticated data banks in the areas of marine ecology, human performance in extreme environments, and the physiology and technology of man in the sea.

A4.1.2 Genesis of the Data System

Both conceptually and in its physical details the Tektite I data system grew out of the project's behavioral program. The predominant orientation of this program was toward the systematic collection of unobtrusive, objective measurements. At the same time the goal was to collect a sufficient number of these measures to produce a full, multidimensional picture of the men and their environment. Because of the anticipated large volume of data that the behavioral observation program would generate, planning for that program was always computer oriented. When it became apparent that other programs would require data management support, it was suggested and agreed that the system being devised for behavior study be extended to include data from those programs. Although this decision was made rather late in the mission planning process (specifically in late July 1968), the intent was not only to provide a means of collecting and handling data but to set up a digital data bank for Tektite I. Those investigators from the other programs who had already established their collection procedures would make their data available for inclusion in the data bank after the mission, along with the measurements that were generated within the system. Thus the behavioral records would form one set (albeit the largest set) in a multicomponent file that also incorporated information from the biomedical, marine science, and habitat engineering programs of Tektite I.

The constraints operating on the development of the data system were severe, so the resulting system could hardly be termed the latest word in data-processing sophistication. The short lead-time has already been mentioned. This time press was aggravated by delays in receiving measure specifications from various participants. Budgetary restrictions were definitely a factor, but they proved far less limiting in equipment purchase or computer time than in the shortage of available programming man-hours. The remote and primitive Tektite I site on St. John in the Virgin Islands imposed its own restrictions, such as cramped space, heat and humidity, fluctuating power, unreliable telephone service, and reliable logistic nightmares. On-site transcription and reproduction services were minimal, as was available training time for those who would be recording the data. Obviously the system had to be kept simple and robust in the face of these afflictions.

A4.2 Description of the Data System

A4.2.1 Data Collection

Nicholas Zill, Bellcomm, Inc., Washington, D.C., and
Lt. Richard Mach, Naval Medical Research Institute,
Bethesda, Maryland

A4.2.1.1 General Description

Machine-readable data were generated at the Tektite I site by manual punching of special, preperforated IBM cards. The cards were punched in IBM 3000 information recorder boards. The information recorder (Fig. A55) is a compact (10 by 9 by 1-1/2

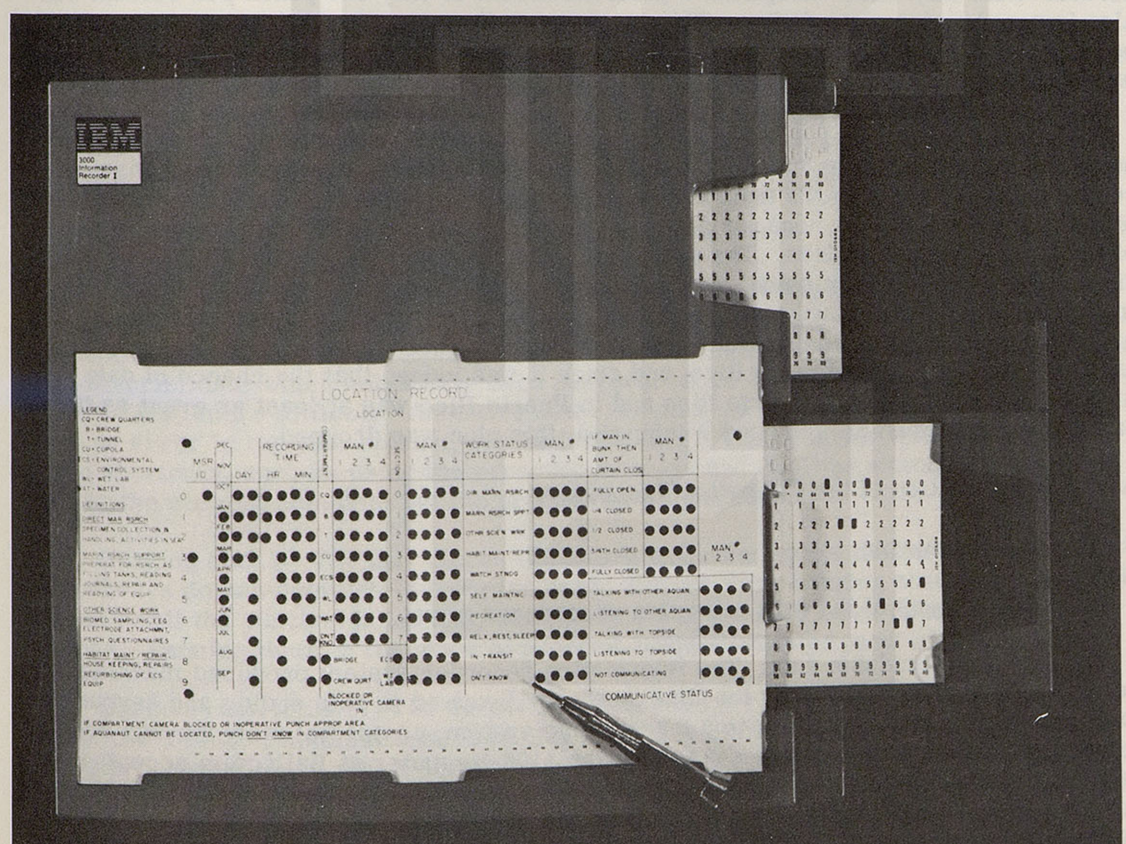


Fig. A55 - The Model I information recorder, with a stylus for punching, preperforated cards, and a sample template, namely, the behavior program's location record inches) predominantly plastic unit with a sliding tray for card insertion, an attached stylus for punching holes, and a template which overlays the card and indicates where and how the data should be entered.

Stock cards were used which contained 40 columns of 12 punch-positions each, the equivalent of every other column on a standard 80-column IBM card. The templates are exchangable sheets of plastic or treated cardboard which have the same configuration of preperforated areas as the cards. However, in designing a template for a particular series of measures, only those holes are punched in the template which expose meaningful punch positions on the card below. The margins and unpunched areas of the template permit the designer to include instructions and definitions of measure categories on the overlay. Not exposing inappropriate punch positions also eliminates the possibility of certain kinds of punching errors.

A standard template format was imposed to allow identification and sorting of each data card: The first two columns contained a unique identification number indicating to which program the data belonged and to which set of measurements within that program the card contributed. The third column indicated the month, and the fourth and fifth columns indicated the day of the month on which the data were collected. This format also provided the basis for organization of the data bank files. The remaining 35 columns of a card were used as specified by the relevant investigators and varied from template to template. However, most templates also included the time of day that the data were recorded. With only a few exceptions a procedural rule of only one punch per column was also imposed on template design. This cut down on the amount of information that could be squeezed into a record, but it simplified user instructions and permitted the sorting program to flag cards with multiple punches in a column as erroneous.

The principal measures in the behavior program were recorded by direct, on-line punching of cards with the information recorders. For the remainder of the behavior records, and for the records from the other programs, data were transferred on site but off-line, from checklists, logs, or paper-and-pencil forms to IBM cards, again by means of the information recorders. The source records for this off-line punching remained on site until the end of the mission, for reference and as a safeguard against data loss in transit. It had been planned to duplicate the on-line cards at a computer service facility in the Caribbean to provide similar safety backups for these data. However, the nearest available facility was in Puerto Rico, and since it was judged that the chance of data loss in transit from St. John to Puerto Rico and in Puerto Rico was at least as great as the same chance between St. John and Washington, this plan was dropped.

A4.2.1.2 Evaluation of the Collection Procedures

A4.2.1.2.1 Advantages

The advantages of the data collection procedures were:

1. Machine-readable data. The information recorder system produced machine-readable data, thus eliminating the time and labor involved in data coding and keypunching. Moreover, and in contrast to a mark-sense system, no special machine was required to read the data; the card reader of the Univac 1108 computer at Bellcomm accepted the cards directly. The lack of intermediate steps created the potential for rapid turnaround from receipt of the data to shipment of organized output and quick-look analyses back to on-site mission personnel. Because of programming-time limitations, this potential was not fully realized during the Tektite I mission.

2. Low cost. The total equipment cost for 11 information recorders, 30,000 stock cards, 70 template cards (prime templates plus spares), card receptacles, and miscellaneous ancillary apparatus was approximately $1400. The bulk of this cost was for the

information recorders (approximately $100 per unit). Substantial effort was involved in design of the individual templates, but similar effort would be required with practically any system — if not in the design of recording forms, then in postrecording coding decisions. Costs were held down by obtaining treated cardboard template blanks which were then prepared in-house at Bellcomm and at the Naval Medical Research Institute, instead of using the plastic templates also available from IBM, which require costly composition and printing. The cardboard templates proved quite durable under extensive use (e.g., in the case of the behavior program's location record, 43,000 record completions).

3. Minimal training required. An adequately designed template provides extensive guidance to the user while he is punching the data. As was mentioned, this is achieved through definitions and labels on the face of the template and through selective masking of inappropriate punching areas on the card. Furthermore the perceptual motor skills involved in punching with the stylus were relatively simple. Thus the training requirements for use of the information recorders are not significantly greater than with paper-and-pencil forms.

4. Speed of data entry. The speed of data entry attainable with the information recorder is less than but comparable to average keystroke rates of experienced keypunch operators. It was certainly adequate for the Tektite I requirements. For example, one of the behavior observers, after about 10 days of experience, punched out the location record shown in Fig. A55 in 12 seconds.

5. Compactness. Because the template eliminates the necessity of repeating descriptive information on each recording form or card, the sheer bulk of needed materials is considerably reduced. Moreover a number of different templates can be used with the same recorder board. Consequently organization of the recording station is simplified.

A4.2.1.2.2 Disadvantages

The disadvantages of the data collection procedures were:

1. Self-checking and correction difficulties. Visual feedback to the user of what has been entered is substantially less convenient with the punchboard than with pencil or keyboard entry systems. It is necessary to look down through the template at the card below and to discriminate which holes have been punched. Once an error has been caught, correction is also more difficult. An entire new card must be punched, which, when one makes an error in the 39th column, can be frustrating. The behavior team developed certain shortcuts, such as using the error-containing card itself as a template for repunching the correct columns, but the process was still tedious.

2. Hanging chads. The tiny pieces of the preperforated cards that are punched out do not always detach completely from the card. Unless these hanging chads are removed, they can refill the punched holes and, when the card is machine read, cause jamming or data loss. Fanning through the stack of punched cards eliminated most of these chads.

3. Format restrictions. The 40-column limitation per card proved restrictive in some of the Tektite I applications. Use of a Model II information recorder, in which two cards are placed under a single larger template, permitted easing of this restriction. However, this meant that at least the first five columns of card-identifying data had to be punched out separately on both cards. Standard Hollerith coding of alphabetic information is impractical with the information recorder because of the difficulty of presenting the necessary instructions on the template. However, it is possible to have meaningful multiple punches in a single column, if a program is written to properly interpret such punching.

4. Reformatting difficulties. The capability of adding new types of data to a predesigned template to meet unforeseen possibilities depends on how full that template is already. A template employing all 40 columns allows little improvisation. However, a template with unutilized columns can incorporate new data by punching out some of these columns and typing or writing new labels on the template. Even with 40 columns, categories can be added to an existing column by punching out an additional hole in the template. However, such midstream changes, a small number of which were necessary in Tektite I, caused headaches for the programmer preparing programs to interpret these cards.

A4.2.1.2.3 Conclusion

In summary, balancing these advantages and disadvantages, the data collection procedures proved quite workable, particularly for the on-line behavior observations.

A4.2.2 Data Logistics
Nicholas Zill, Bellcomm, Inc.

The stock cards were stored in the air-conditioned support van at the Tektite I site in Lameshur Bay. This is also where most of the data entry took place. The total number of cards required over all programs was 30,000 (including a 50% surplus margin). The storage space required was less than 10 cubic feet.

Punched cards were shipped out approximately once a week. Cards from the various programs were packed together (for minimum package size) in one box, which had also been used for stock card storage. Because of the vagaries of Caribbean cargo handling, cards were shipped out only when they could go as the personal luggage of an individual returning to Washington from the mission site. Even then the courier was encouraged to carry the box aboard the plane with him. The only data casualties sustained in-transit occurred when an overzealous Pan Am clerk stapled a baggage check onto a card box, mutilating the tops of a number of cards. Happily the data on those cards were saved, but at a cost of repunching duplicate cards by hand.

In Washington the cards were incorporated into the digital data bank at Bellcomm. When computer printouts were available, they were flown back to St. John with mission personnel returning from Washington.

A4.2.3 Data Processing
Anita Cochran, Bellcomm, Inc.

The computer installation at Bellcomm consists of a Univac 1108 with two Fastrand drums, five 423H high-speed drums, eight VII-C tape drives, one 758 high-speed printer, and three Univac 1004's used primarily as peripheral devices for the computer. The 1108 is a 36-bit-word machine with an add speed of 750 nanoseconds. The Bellcomm installation has a core of 165,000 bits.

The first step in processing, reproduction of the manually punched cards into standard machine-punched cards, was attempted on the 1108. At the high speed required, however, many cards jammed, and the process of recovering the data was long and painful. A 1004 computer was then taken off-line. With the resulting decrease in speed of the card reader the problems almost disappeared, and reproduction of the remaining data cards was accomplished with relative ease. Less than 0.1% of the data cards were partly or wholly lost due to mechanical difficulties. The card images were written on magnetic tape from the reproduced cards.

CREATE COMPLETE DATA TAPE DATE 120569 PAGE 297

63220	2315	21	1	1	1	1		
63222	0230	21	1	1	1	1		
63224	2330	21	1	1	1	1		
63227	0930	21	1	1	1	1		
63305	2230	21	1	1	1	1		
63306	1203	0	509+					
63306	2200	21	1	1	1	1		
63307	2200	21	1	1	1	1		
63308	2015	21	1	1	1	1		
63309	2320	21	1	1	1	1		
63310	2200	21	1	1	1	1		
63311	2300	21	1	1	1	1		
63312	2130	21	1	1	1	1		
63313	2320	21	1	1	1	1		
63314	2320	21	1	1	1	1		
63315	2230	21	1	1	1	1		
63316	2215	21	1	1	1	1		
63317	2115	21	1	1	1	1		
63317	2123	3				73	7+	
63318	2255	21	1	1	1	1		
63319	2350	21	1	1	1	1		
63323	2115	21	1	1	1	1		
63325	0030	21	1	1		1		
63325	2230	29	9	9	9	9		
63326	2330	21	1	1	1	1		
63327	2300	31	1	1	1	1		
63328	2330	21	1	1	1	1		
63329	2330	21	1	1	1	1		
63331	2330	29	9	9	9	9		
63401	2300	29	1	1	9	9		
63402	2400	29	1	9	9	1		
63403	2200	39	1	9	9	1		
63404	2100	29	1	9	9	1		
63405	2330	29	1	9	9	1		
63406	2400	21	1	9	9	1		
63407	2330	21	1	9	9	1		
63408	2300	21	1	9	9	1		
63410	2235	29	9	9	9	9		
63411	2340	21	1	9	9	1		
63412	2320	21	1	9	9	1		
63413	2400	21	1	9	9	1		
64000	00							
64216	23552	2 652	25078	08750		44086	54850	83148
64218	03152	2 602	25077	08750		43756	44849	82147
64218	16152	2 602	25078	08751		43086	44750	83147
64220	2320	2 652	25 77	8752		45 76	44950	84148
64222	0230	2 602	50 77	8952		48 76	45049	84147
64224	2330	2 652	30 77	8751		45 76	34950	84148
64225	16454						5252	86
64227	0930	2 602	45 77	8850		42 56	24850	83147
64302	1715	2 572	47 77	8948		39046	04849	82147
64305	1900	2 552	48 78	8950		39 76	34749	82147
64306	2200	2 602	28 77	8752		43 76	44950	83147
64307	2200	2 522	50 77	8954		41147	14849	83147
64308	2030	2 602	55 78	8954		43157	14950	84148
64309	2330	3 572	52 78	9053		43147	35149	85147
64310	2200	2 552	52 78	9053		43147	24950	84147
64311	2300	2 632	56 78	8954		43157	24950	8414

Fig. A56 - A sample page of output from TKSORT, the computer program which sorted the card images by record identification number and date and stored them on magnetic tape

Two major programs were written to handle the raw data. The first of these, called TKSORT (approximately 1200 statements), was designed to read the card images from tape, eliminate cards with obvious errors, sort the data according to measure identification number, put them in chronological order within the measure groups, and in some cases sort again within the dated measure groups with respect to certain parameters. The sorted data were then stored on magnetic tape. A sample of the output from TKSORT is presented in Fig. A56.

The second major program, called TKPRNT (approximately 3000 statements) was designed to print the sorted data in appropriately labeled tables. It had been planned to incorporate checks of error in magnitude of certain entries and include notations of such error in the tables. However, the short time available made it impractical to include this capability. A sample of the output from TKPRNT is presented in Fig. A57.

Documentation is available from Bellcomm for both programs, including listings of the programs.

The sorted Tektite I data have been stored in three files on tape. File 1 contains the biomedical data. File 2 contains the behavioral data, and file 3 contains the habitat technology data. Within each file, data are stored 32 records to a block, where each record is the equivalent of one data card. Blocks are 256 words long, except that the last block in the file may contain fewer records, hence fewer words. The data cards were punched in even-numbered columns on 80-column cards. Each card image was packed into eight words, with each word containing five characters and a blank as follows, where α is an alphanumeric character, b is the blank, and a number is the number of the bit at the beginning of the character:

0	6	12	18	24	30
α	α	α	α	α	b

Records are written in Univac field-data character codes. There are no extraneous words on the records or in the record blocks. The tape is seven-track, written at 556 bits per inch with odd parity.

A4.3 Use of the Data System by Mission Programs

A4.3.1 Biomedical Data
Nicholas Zill, Bellcomm, Inc.

Two templates were designed at Bellcomm in cooperation with Dr. T. Markham for recording data on the general medical condition of the aquanauts. Template 11, the medical status assessment, is illustrated in Fig. A58. The symptoms and treatment record (template 12) made use of a page overlay assembly instead of the single-sheet templates used in the other records. This is a bookletlike arrangement which opens to expose a limited number of punching columns. It permits a great deal more descriptive information to surround the columns and guide punching. Data for both of these records were punched off-line in the support van from information in the medical log.

Microbiology data were punched postmission with information recorder templates designed by Lt. A Cobet. Respiratory parameter data from Dr. C. J. Lambertsen and hematology measures from Dr. C. Fischer were entered into the data bank postmission via conventional keypunching.

A listing of the biomedical program records is presented in Table A45. All of these records contain relevant values from pre- and postmission medical examinations.

LEGEND:

READ BY	COMPRESSOR OIL LEVEL	COOLANT LEVEL-TANK	FREON.LIQUID LINE
0=TOPSIDE	1=NORMAL	4=NORMAL	7=CLEAR
1-4=AQUANAUT IDENTIFICATION	2=LOW	5=FLUID ADDED	8=SOME BUBBLES
9=MORE THAN TWO AQUANAUTS	3=LOW, OIL ADDED	6=FLUID DRAINED	9=MANY BUBBLES

NOTE: FLOW RATE=COOLANT FLOW RATE TO HEAT EXCHANGER
OIL LEVEL=COMPRESSOR OIL LEVEL

DATE	TIME	READ BY A	READ BY B	COMPRESSOR PRESSURE SUCTION	COMPRESSOR PRESSURE DISCHARGE	CONDENSER TEMP INLET	CONDENSER TEMP OUTLET	COOLANT TEMP INLET	COOLANT TEMP OUTLET	COOLANT PRESS. INLET	COOLANT PRESS. OUTLET	FLOW RATE FM8	FLOW RATE FM9	FLOW RATE FM10	OIL LEVEL	COOLANT LEVEL	FREON
0/00	00																
2/16	2355	2	2	65	225	078	087	50	44	08	65	4.8	5.0	8.3	1	4	8
2/18	0315	2	2	60	225	077	087	50	43	75	64	4.8	4.9	8.2	1	4	7
2/18	1615	2	2	60	225	078	087	51	43	08	64	4.7	5.0	8.3	1	4	7
2/20	2320		2	65	225	77	87	52	45	7	64	4.9	5.0	8.4	1	4	8
2/22	0230		2	60	250	77	89	52	48	7	64	5.0	4.9	8.4	1	4	7
2/24	2330		2	65	230	77	87	51	45	7	63	4.9	5.0	8.4	1	4	8
2/25	1645	4										5.2	5.2	8.6			
2/27	0930		2	60	245	77	88	50	42	5	62	4.8	5.0	8.3	1	4	7
3/02	1715		2	57	247	77	89	48	39	04	60	4.8	4.9	8.2	1	4	7
3/05	1900		2	55	248	78	89	50	39	7	63	4.7	4.9	8.2	1	4	7
3/06	2200		2	60	228	77	87	52	43	7	64	4.9	5.0	8.3	1	4	7
3/07	2200		2	52	250	77	89	54	41	14	71	4.8	4.9	8.3	1	4	7
3/08	2030		2	60	255	78	89	54	43	15	71	4.9	5.0	8.4	1	4	8
3/09	2330		3	57	252	78	90	53	43	14	73	5.1	4.9	8.5	1	4	7
3/10	2200		2	55	252	78	90	53	43	14	72	4.9	5.0	8.4	1	4	7
3/11	2300		2	63	256	78	89	54	43	15	72	4.9	5.0	8.4	1	4	
3/12	2130		2	65	232	78	88	52	44	15	71	4.9	4.9	8.3	1	4	
3/13	2325		2	55	255	78	90	52	41	15	71	4.8	5.0	8.3	1	4	7
3/14	2330		2	58	230	78	88	50	41	14	72	4.8	5.0	8.3	1	4	7
3/15	2245		2	55	225	78	88	50	42	15	71	4.9	5.0	8.3	1	4	7
3/16	2225		2	62	230	78	88	52	43	15	72	4.9	5.0	8.4	1	4	
3/17	2210		2	056	252	078	89	52	42	15	72	4.8	5.0	8.3	1	4	
3/18	2250		2	58	255	78	89	54	43	15	72	4.9	5.1	8.5	1	4	
3/19	2355		2	58	225	78	87	51	43	14	72	5.0	4.9	8.4	1	4	
3/20	2330		2	55	253	78	89	52	41	14	72	4.8	5.0	8.3	1	4	
3/21	2355		2	58	255	78	92	54	43	14	72	4.9	5.0	8.3	1	4	
3/22	2330		2	53	253	78	89	51	40	14	72	4.8	5.0	8.2	1	4	7
3/23	2315		2	55	237	78	88	54	45	15	71	4.9	5.0	8.4	1	4	7
3/25	0030		2	056	254	078	090	52	41	15	72	4.8	5.0	8.3	1	4	
3/25	2230		2	055	255	078	090	52	41	15	72	4.9	5.0	8.4	1	4	
3/26	2330		2	064	235	078	087	53	44	15	72	5.0	5.1	8.5	1	4	7
3/27	2300		2	065	233	077	087	53	44	15	72	4.9	5.0	8.4	1	4	
3/28	2345		2	062	232	077	087	51	45	15	72	4.9	5.1	8.4	1	4	7
3/29	2330		2	062	253	077	087	52	44	15	72	5.0	6.1	8.5	1	4	
3/31	2340		2	055	255	077	089	49	40	14	71	4.7	5.0	8.3	1	4	
4/01	2300		2	056	256	077	089	49	40	14	72	4.8	5.0	8.3	1	4	
4/02	2400		2	057	257	077	089	48	40	14	72	4.8	5.0	8.3	1	4	7
4/03	2200		2	058	260	078	089	49	40	14	72	4.8	5.0	8.3	1	4	7
4/04	2100		2	056	237	078	087	52	45	14	72	4.9	5.1	8.5	1	4	7
4/05	2330		2	058	260	077	089	50	42	14	72	4.9	5.0	8.4	1	4	7

Fig. A57 - A sample page of output from TKPRNT, the computer program which printed the sorted data in appropriately labeled tables

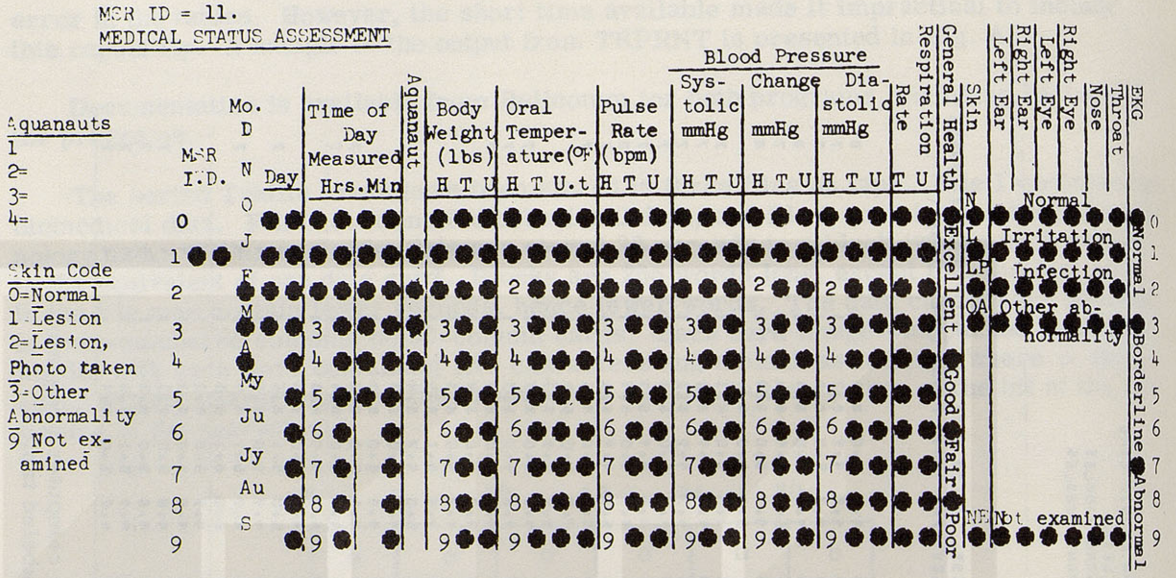


Fig. A58 - The medical status assessment record, a sample template from the biomedical program. (Aquanaut names have been deleted.)

Table A45
Medical Program Records (File 1) in the Data Bank Tape

Measure Records Identification Number	Record Name	Responsible Investigator
11	Medical status assessment	Markham
12	Symptoms and treatment record	Markham
13	Hematology record (I)	Fischer
14	Hematology record (II)	Fischer
15	Serum/chemistry record	Fischer
16	Electrophoresis record	Fischer
17	Humoral and cellular immune responses	Fischer
18	Red cell mass and survival	Fischer
19	Pulmonary function record (I)	Lambertsen
20	Pulmonary function record (II)	Lambertsen
21	Aerobiology record	Cobet
22	Bacteriology record	Cobet
23	Interchange record	Cobet
24	Mycology record	Cobet
25	Pollution record	Cobet
26	Virology record	Cobet

A4.3.2 Behavioral Data

Lt. Richard Mach, Naval Medical Research Institute,
Bethesda, Maryland, and Nicholas Zill, Bellcomm, Inc.

A listing of the types of records employed in the behavior program is presented in Table A46. This table also indicates the input mode of each record. "On-line" indicates behavioral data that were punched onto the preperforated cards as it was observed. "Off-line" indicates data that were collected in checklists or logs and then transferred to cards by manual punching at the mission site. The rest of the records were transferred from data sheets by conventional keypunching after the mission was over. Since a thorough description of behavioral collection procedures was given in section A2.2, the present consideration will be confined to design and fabrication of the behavioral templates.

In designing the formats of on-line observation templates the purpose was to organize each different record in as simple and straightforward a manner as possible. Most often the chronology or strict time-sequence of particular events was employed in preparing the format. The order on the template, from left to right, of the separate aspects of the measure mimicked the actual order of occurrence of those aspects. This is illustrated in the dive record (Fig. A59). Space on the card was saved by not repeating the hours

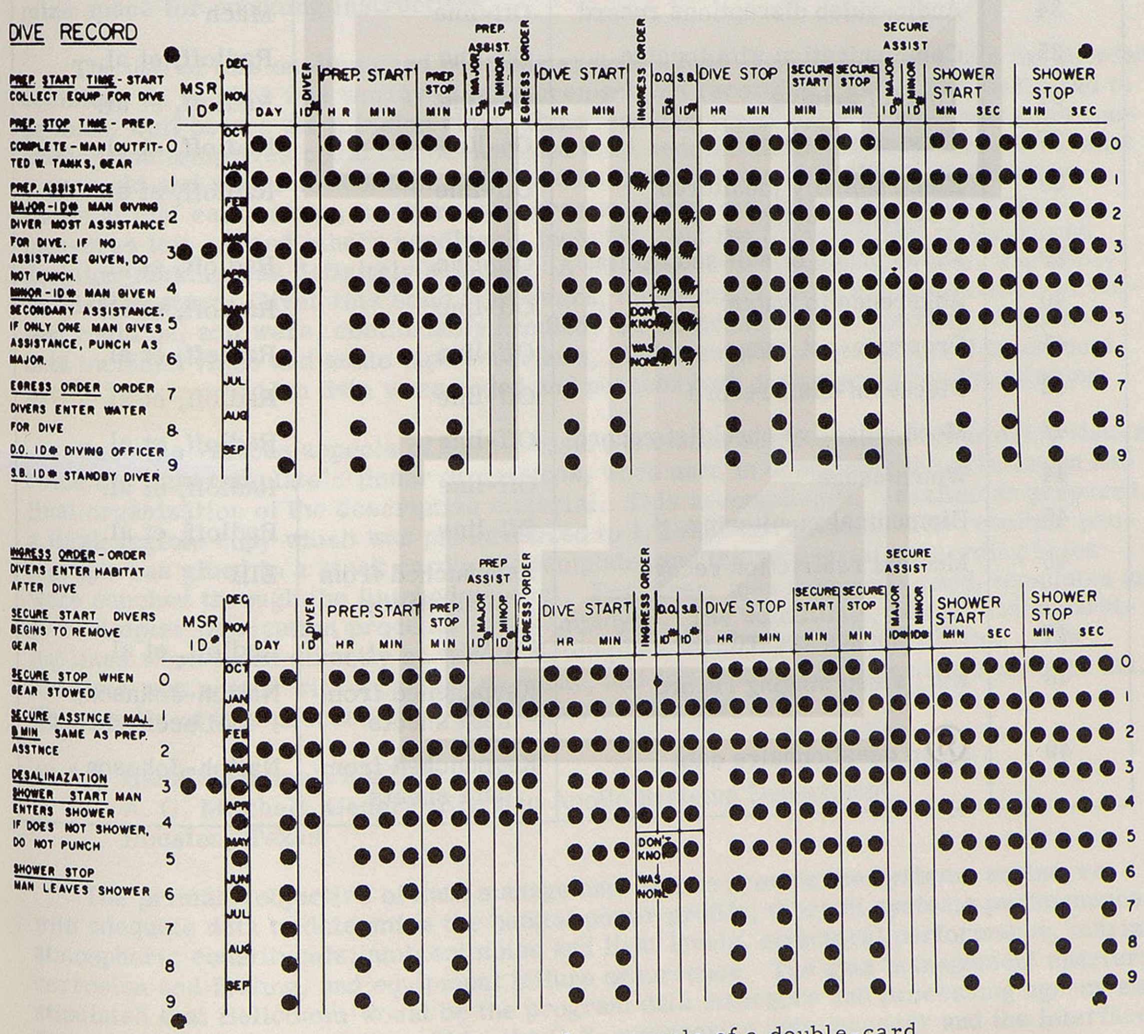


Fig. A59 - The dive record, a sample of a double-card template from the behavior program

Table A46
Behavior Program Records (File 2) in the Data Bank Tape

Measure Record Identification Number	Record Name	Input Mode	Responsible Investigator
27	Maintenance and repair record	Off-line	Zill
29	Psychomotor test record	Keypunched from data sheets	Saucer-Scow
30	Location record	On-line	Radloff, Mach, Zill, and Helmreich
31	Transit record	On-line	Radloff, et al.
32	Meal behavior	On-line	Radloff, et al.
33	Dive record	On-line	Radloff, et al.
34	Audio-video disruptions record	Off-line	Mach
35	Communication with topside	On-line	Radloff, et al.
36	Time of arising	On-line	Radloff, et al.
37	Time of retiring	On-line	Radloff, et al.
38	Electronically monitored facilities usage	Off-line	Radloff, et al.
39	Maintenance of self and habitat	Off-line	Radloff, et al.
40	Adherence to watch	Off-line	Radloff, et al.
41	Pressure-pot usage	Off-line	Radloff, et al.
42	Pieces-of-mail record	Off-line	Radloff, et al.
43	Mood adjective checklist record	Off-line	Radloff, et al.
44	Winch usage	Off-line	Radloff, et al.
45	Biomedical monitoring	Off-line	Radloff, et al.
46	Medical restriction record	Keypunched from medical log	Zill
47	EEG hookup record	On-line	Radloff, et al.
48	EEG sleep staging record	Keypunched from data sheets	Naitoh-Johnson, DeLucchi-Frost
49	Sleep questionnaire data	Keypunched from data sheets	Naitoh-Johnson

columns for time of occurrence when it could be anticipated that the hour designation would be redundant, and the hours columns could instead be filled in by card reading and analysis programs. During the collection of records that involved the start and stop times of lengthy actions (e.g., a dive) the observers found it convenient to leave the stylus in the last hole punched, as a reminder of where they were in the punching sequence when data entry resumed.

The recording of specific events when and only when they occurred was not the only sampling technique employed. For instance the location, activity, and communicative status of the individual aquanauts were noted and punched at certain prespecified times. Chronology was no longer a factor here, since sampling of these different considerations was to be theoretically simultaneous. The question then was how to organize a template that treated four men over a number of parameters. Although the observer procedure was to be man locked, i.e., observing everything required about a given aquanaut before proceeding to the next aquanaut, it proved more convenient to set up the template in an event-locked format. As is shown in Fig. A55 this format had four columns for the four aquanauts clustered together under the first parameter, then four more columns for the next parameter, etc. This allowed more descriptive information about the parameters to be printed on the template and did not interfere significantly with the observation procedure. Note also in Fig. A55 the way in which punching fields can be staggered to maximize space for punching instructions.

The use of this on-line card punching system forced the investigators into hardheaded decisions as to what was worthy of measurement and recording. These judgments had to be made well before the mission start, since manufacture of the templates was time consuming and templates could not be designed until commitments had been made as to what they would and would not contain. All the details of mission procedures could not be known at that early stage, so there of course were regrets during the mission about measures left out and others needlessly included. But the overall effect of the forced decision-making was definitely salutary. A workable well-organized system was ready at mission start. Given this solid framework, minor corrections and additional information could be, and were, comfortably handled. Provisions for incorporating additional data included video and audio tape recorders, slight template revisions, and an unusual-events log, from which data were coded and punched both during and after the mission.

Once the various aspects of each measure had been decided on, image overlay sheets, twice the final template's linear dimensions, were used in developing the orientation and final organization of the descriptive material. This accomplished, a draftsman prepared a final, legible copy which was photoreduced to 1/2 size and printed. The resultant photograph was glued to a stock cardboard template, and the appropriate recording holes were punched through the finished product. For other, less frequently used, templates an even simpler fabrication procedure was employed. The definitions, labels, and separating lines were typed directly on the blank template with an electric typewriter. The template was coated with a protective spray, and the appropriate holes were punched out. The results of this process were also highly satisfactory.

A4.3.3 Habitat Engineering Data

A. G. Mitchell, General Electric Apollo Systems Department,
Houston, Texas

The primary objective of data management was to provide the systems engineers with adequate data to determine the habitat power profile, thermal systems performance, atmospheric constituents, ambient noise and light levels, structural performance, marine corrosion and fouling, and equipment failure occurrence. The data management charters stipulated that Bellcomm would be the program data managers and processing agency and General Electric, Houston, would be the G.E. engineering data manager and the interface with Bellcomm. The data management responsibilities included the definition of requirements, acquisition, preprocessing and insertion of raw data into the Bellcomm processing machinery.

A data meeting with G.E. engineering and Bellcomm was held at General Electric, Valley Forge, on December 19, 1968, to discuss the recording and processing requirements of the engineering measurements. This meeting established the general recording requirements for the engineering data for all systems and the processing requirements for the electrical power systems. Bellcomm accepted the responsibility for generating the data-recording forms for use in the habitat and the IBM-information-recorder overlays for all the engineering data. Following this meeting the Bellcomm and G.E. Apollo Systems Department representative adjourned to the Philadelphia Navy Yard to tour the habitat. The Bellcomm representative spent 2 hours reviewing the habitat measurement indicators to determine their readability and accessibility. Bellcomm generated the data recording forms for use in the habitat and the engineering information-recorder overlays on the basis of the information obtained at the meeting and tour of the habitat. General Electric data management generated the engineering-data recording forms for use on the surface.

General Electric program and data representatives met with Bellcomm on January 30, 1969, to review the engineering data program, habitat data-recording forms, and the information-recorder overlays. It was agreed that G.E. would provide the engineering information recorder, that the engineering data would be punched into IBM cards on site, and that the cards would be turned over to the Bellcomm on-site representative. A review of the habitat and surface data-recording forms proved them to be acceptable. All the information-recorder overlays could not be reviewed, as they were not complete. It was established that G.E. habitat engineers would be provided with computer printouts of the raw data and that a magnetic tape copy of the data files would be forwarded to General Electric, Houston, when it was complete. The final listing of the records employed is given in Table A47. Template 64, the engine room measures, is shown in Fig. A60.

The data acquisition plan was straightforward and simple. Bellcomm provided notebooks containing pressure-sensitive data-recording forms. Each of the notebooks was placed within the appropriate habitat compartment prior to the mission start. Surface data-recording forms were placed within the support van. Bellcomm instructed the aquanauts on the procedure for and the importance of faithfully completing the data forms, and the G.E. data representative instructed the G.E. technical watch monitors concerning the surface data-recording procedures. Bellcomm designated the behavioral program supervisor as the on-site data interface and requested that G.E. submit raw engineering data through this channel.

Habitat data were to be recorded daily during the peak load period of the systems (expected to occur during evening meal preparation). Surface data would be recorded every 2 hours from mission start to mission completion. Completed surface data-recording forms would be stored in a notebook and remain within the support van for reference. Once each day the G.E. data representative would transfer the surface data onto IBM cards for submittal. The hard copy of the habitat data would be sent to the surface each day, addressed to G.E. The Department of Interior representatives, who received the material, equipment, etc., sent to the surface, then delivered the data to the G.E. data representative. These data would be transferred to IBM cards, combined with surface data cards, and submitted to the Bellcomm data interface daily. Once each week the total program data would be forwarded to Bellcomm for processing. A printout of the engineering data was to be made available during the mission, containing processed data for mission days 1 through 30, and a final output containing all the engineering data would be distributed after mission completion. The data would be distributed direct

Table A47
Habitat Engineering Records (File 3) in the Data Bank Tape (Responsible Investigators: A. G. Mitchell and B. P. Tenney of General Electric)

Measure Record Identification Number	Record Name	Parameters Contained
60	Habitat environmental survey	Temperature; humidity; noise levels
61	Thermal adjustments record	Thermostat resettings
62	Emergency air measures	Emergency air supply pressure and breathing system pressure. Bibb line pressures. Status of Bibb flow control valve and emergency bottles.
63	Alarms, Drills, and Emergencies	Time; nature; time required to perform or correct
64	Engine room measures	Compressor pressures; condenser temperatures; coolant temperatures, pressures, flow rates, and level; oil level; Freon liquid line status
65	Baralyme change record	
66	Communication, appliances, anomalies	Intercom supply voltage; communication battery voltage; isolated ac voltage and current; freezer temperature; nature and correction time of anomalies
67	Topside measures	Instantaneous 440-V power to habitat; maximum power demand, total power supplied; water consumed; nitrogen bottle and line pressures; nitrogen flow rate
68	Atmosphere monitoring and mass spectrometer status	Absolute pressure in habitat; partial pressures of oxygen, carbon dioxide, water vapor, and nitrogen. Flow rate into habitat. Flowmeter discharge pressure. Purge valve status; mass spectrometer status; ion and anode current; battery voltage.
69	Backup atmosphere monitoring	Percent oxygen; carbon dioxide from backup meters; hydrocarbons; carbon monoxide; particulate matter; detector tube readings
70	Diving systems and underwater maintenance	(Not recorded after mission start)
71	Maintenance and repair record	(Repeat of Record 27)
72	Daily weather report from St. Thomas	

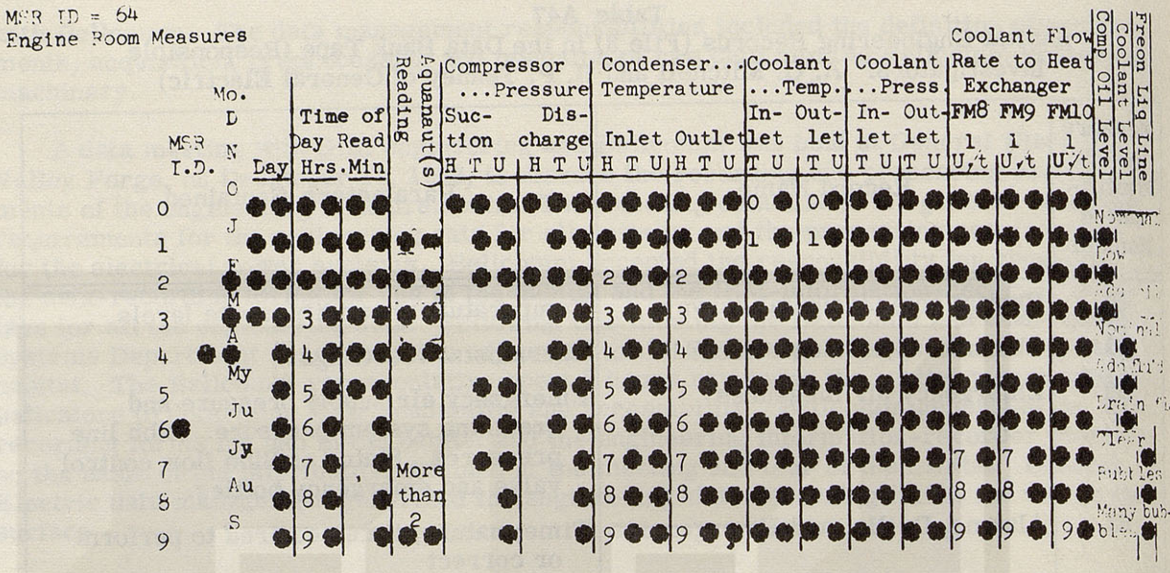


Fig. A60 - The engine room measures record, a sample template from the habitat engineering program. (Aquanaut names have been deleted.)

from Bellcomm according to a list provided by G.E. At a future date the data contained within the Bellcomm data bank of a nonsensitive or nonproprietary nature would be made available to the oceanographic community.

Implementation of the data plan was not quite as anticipated. Data acquisition was the primary problem and ranged from ransoming the habitat data from the aquanauts with an electric food blender to recording the instantaneous power levels with personal wrist watches instead of the more accurate stopwatch provided. Prior to the mission the aquanauts complained of the magnitude of habitat engineering data. Bellcomm made a special trip to the site to review, justify, and explain the requirements. A walk-through of the measures was performed to demonstrate that the time required to record them was not prohibitive. The aquanauts reluctantly agreed to record the data. Once the mission was in progress and the daily activities settled into routines, it became apparent that the aquanauts were not recording habitat data as requested. When questioned they again expressed their unhappiness with the magnitude of the data and time required to accomplish the task. A compromise was reached on March 15, 1969, between the aquanauts and the G.E. program representative; the aquanauts agreed to record daily the temperature and humidity in all four compartments and certain of the bridge and engine-room parameters.

The data recording on the surface was straightforward except for the habitat instantaneous power parameter and the mass spectrometer correction factors. In approximately 10% of the instantaneous power recordings the time required for 10 revolutions of the watt-hour meter disk was measured with a wristwatch instead of with the stopwatch provided in the van. Such readings were recorded in whole seconds instead of with the accuracy achievable with the stopwatch, which was plus or minus 0.2 second.

The personnel who were the G.E. surface data recorders were not adequately briefed on the application of the mass spectrometer correction factors. The accuracy of early mass spectrometer data is therefore questionable. In some cases the correction factors were correctly applied, in some cases completely ignored, and in other cases applied in the wrong direction. To compensate for this, additional, accurately corrected mass spectrometer data from the medical log were entered into the data bank by Bellcomm after the mission. These additional data are flagged with a "+" in the data-recorder column. A calibration history of the mass spectrometer is also available from G.E. or the data bank.

General Electric data management was also remiss in thoroughly checking out the readability (for recording accuracy) of the habitat and surface instrumentation indicators. Consequently, the information-recorder overlays did not, in several cases, allow for transferring data onto IBM cards as accurate as was available.

Early in the mission it became apparent that the water-partial-pressure indication of the mass spectrometer was erroneous. The sensor was the culprit, and this reading should be ignored. Additional habitat atmospheric instrumentation was added to the gas chromatograph sample line (to the author's knowledge, the gas chromatograph never functioned properly). For a period of time the habitat atmospheric monitor was provided with three oxygen and two carbon dioxide partial-pressure indications.

The information-recorder overlay provided very stringent data formats. Several innovations were required to enter special-case information into the data processing system. For example it was not anticipated that additional CO_2 scrubbers would be required, so the template containing the baralyme change history (template 65) did not differentiate between the prime or auxiliary baralyme scrubbers (not to mention the vacuum cleaner). Therefore special flags were used to indicate prime, auxiliary, or both baralyme scrubber changes.

Engineering data output was reviewed at a meeting in Washington approximately midway through the mission. This review provided a thorough analysis of the output procedures and formats and allowed the recovery of several pieces of mispunched data. Bellcomm was instructed to withhold distribution of these data and submit only the final complete data listing, as the concerned G.E. data users were busily involved with mission operation.

In summary, sufficient Tektite I habitat and surface engineering data were obtained to permit a generalized qualitative engineering evaluation of the habitat and the performance of its subsystems. A quantitive engineering evaluation of the electrical power system can be accomplished. However, the accuracy of approximately 10% of the instantaneous power calculations are questioned because of recording technique. The habitat atmosphere and airflow data can be quantitatively evaluated using the data compiled in the computer printout. The evaluation of the remaining habitat systems should be generalized due to the few recorded data.

In future operations a greater commitment must be made by program management and habitat systems engineering to engineering data management services. These services should provide a check and countercheck mechanism, through the instrumentation system, to determine the adequacy of measurements and to provide an interface between the data processing facility and the design engineers. Data management personnel should be participating parties of early program definition meetings. Data management participation would: establish a data awareness, determine if existing instrumentation is adequate, and provide ample data-programming lead time.

Data management must meet with all data recording personnel, including the aquanauts, to emphasize the importance of faithful and accurate data recording. Data management should provide written data-recording instructions. Data-recording forms should be formulated with both the data recorder and data transcriber in mind and be simple to interpret and complete.

A4.3.4 Marine Science Data
Nicholas Zill, Bellcomm, Inc.

A major disappointment to aspirations for the data system was the limited attempt to incorporate measures from the marine sciences into the collection scheme and the subsequent failure to realize inputs of such information into the data bank. The potential benefit to the marine science program and the project as a whole from coordination of marine science with the data system was considerable, but that potential was not fulfilled. For example, systematic observations from the habitat of underwater environment parameters and ecological censuses would have been quite compatible with the data procedures described. Although such data were stated goals of the marine science endeavor, appropriate procedures remained undefined at the start of the mission; consequently, observations were not carried out systematically during the mission.

Two information-recorder templates were prepared, in cooperation with members of the prime crew, for use by topside marine-science support personnel on site. Neither was used successfully. The projected sequence saw the scientist-divers, in one case, collecting sediment samples from various areas around the habitat and, in the other, recording lobster population data on velum pads with crayon. The labeled samples and the lobster data, transferred to prepared forms, would be regularly sent to topside in the pressure pots. At the base camp, size and composition analysis would be performed on the sediment; the lobster notations would be combined with parallel information collected by the backup aquanauts; both types of data would then be punched onto cards with the prepared templates.

In both cases the difficulties that prevented the completion of this plan were changes in the scientific programs as a result of conditions and experience in the habitat. Time required for other, more primary, geological work did not permit collection of a substantial number of sediment samples. For the lobster program the suitable descriptions and important aspects of lobster behavior were so extensively redefined due to the knowledge gained in the habitat that the template was no longer appropriate. Communication inadequacies prevented the necessary extensive revision of the template.

These difficulties were, however, only specific aspects of a more general and significant problem. The aquanauts were not allotted the sufficient premission time and assistance by the Tektite I project in general, and by their agency in particular, necessary to define and develop a well-integrated, systematic program of research. Coordination between the crew members and data management personnel was hampered by geographical distance and the press of obligations. Conducting marine science from undersea habitats is, of course, a new and evolving endeavor. Tektite I was but a preliminary exploration of optimum ways to use such habitats for marine biological, geological, and oceanographic research. However, those optimum ways will not be found unless future programs allow for thought, preparation, and resources for data collecting and analysis to match the complex interrelationships of the marine environment. It is not sufficient to put scientists underwater and see what they come up with.

A4.4 Secondary Processing and Retrieval
Nicholas Zill, Bellcomm, Inc.

An initial postmission distribution to appropriate Tektite I participants was made of copies of the data tape and computer-printed data tabulations. As of this writing, secondary processing of the data bank contents is nearing completion. This includes:

1. Editing of recoverable errors. Recoverable errors and omissions in the original punching of data are being corrected within a complete, sorted deck of cards punched from the data tape. When correction is complete, the deck will form the basis for a new

tape. Recovery is made possible through reference to raw data sheets, mission logs, and checking against data from other record types. Most errors involving missing identification numbers or dates were caught and, when possible, corrected before the initial distribution of tapes and printouts. Unrecoverable but obviously erroneous data are being deleted.

2. Insertion of additional data. The final data tape will contain additional data which consist either of analyzed results from the present raw data or new data coded from mission logs, audio tape recordings, and other analog records. The logs of which there are copies at Bellcomm include: the watch director's log, G.E. engineering logs, medical log, pressure pot log, decompression log, behavior observers' unusual-events log, and the scientific coordinator's log.

The contents of the data bank are available from Bellcom in the form of magnetic tape, punched cards, or printout. Prior approval must be obtained, however, from the investigator responsible for the particular records desired. A list of these investigators is included in Tables A45, A46, and A47. Further documentation of the data system procedures, including reproductions of all the template formats, is also available from Bellcomm.

A4.5 Conclusions and Recommendations

Nicholas Zill, Bellcomm, Inc.

Although original conceptions were optimistically ambitious, the goals of an integrated data system and a digital data bank were substantially realized for three of the four technical programs in Tektite I. Of the useful functions that a data bank can serve, listed in the introduction, all were performed to at least a limited degree by the Tektite I system. Particularly gratifying has been the crossreferencing between biomedical, behavioral, and engineering data that has already occurred for extension and clarification of various analyses. Certainly, more sophisticated systems than the present one can be envisaged and should be attempted in future undersea habitat operations. However, the reader with visions of on-line computers and cathode-ray-tube displays should realize that the cost of such a system would probably approach the total cost of the Tektite I project.

In conclusion the following suggestions are offered to those who would attempt data management of multidisciplinary field operations in the future:

- An integrated data system and a digital data bank are desirable and achievable goals for such projects.

- The achievement of these goals does not require a vast expenditure of funds but does require realistic allotments of manpower and preparation time.

- The data collection and processing systems should be kept simple and employ devices and procedures that do actually, rather than potentially, work.

- Programming elegance should be sacrificed for flexibility and ease in modifying programs to meet necessary changes in data formats.

- The process of editing data for errors and omissions should be made as streamlined as possible.

- Finally, data management personnel should be prepared for an experience similar to that of the Little Red Hen in the nursery tale. When the Little Red Hen asked, "Who will help me bake my bread?", she found few takers. But when the bread was baked and she asked, "Who will help me eat my bread?", the helpers flocked in insistent abundance.

A4.6 Acknowledgments
Nicholas Zill, Bellcomm, Inc.

The principal members of the data management team for Tektite I and contributers to this section A4 of this report were Lt. Richard S. Mach, MSC, of the Naval Medical Research Institute, who had primary responsibility for behavioral data collection but participated extensively in the coordination and execution of all of the data management endeavor, A. G. Mitchell of the General Electric Apollo Systems Department, who served as the engineering data manager, and Mrs. Anita J. Cochran of Bellcomm who accomplished a great deal of programming in a very short time. Mrs. Cochran was assisted in part of her effort by Miss Nancy Robinson. Thanks are due to also the following individuals for their exceptional cooperation in various parts of this effort: W. A. Clark and R. Ohls of IBM; R. Scarlatta of General Electric; A. P. Lepera, N. R. Farmer, and W. O. Robinson of Bellcomm Reproduction Services; and E. E. Hilyard and members of his Computer Operations Group at Bellcomm.

Appendix B

ENGINEERING

B1 DESCRIPTION OF THE FACILITIES SYSTEM

Cdr. W. J. Eager, Naval Facilities Engineering Command,
Washington, D.C.

B1.1 Introduction

The function of the Tektite I facilities system was: (a) to support four aquanauts in their undersea research mission, (b) to support surface personnel in collection and analysis of engineering and scientific data and, (c) to support personnel who constructed, operated, and maintained the complete facilities system. The Office of Naval Research (ONR) was the overall Tektite I project manager, and ONR managed development of the habitat and way station systems. The Naval Facilities Engineering Command and Amphibious Construction Battalion Two developed the remainder of the facilities system.

B1.2 The System

The Tektite I facilities consisted of the several major subsystems shown schematically within Greater Lameshure Bay, St. John, Virgin Islands in Fig. B1. The base camp provided hotel, medical, and administrative facilities for a maximum of 110 support and scientific personnel. The base camp (with water and electrical systems) and the road were designed, constructed, operated, and maintained by the Seabees of Amphibious Construction Battalion Two. The causeway pier served as a terminal for transportation of material and personnel between St. Thomas Island, the base camp, and the support barge. The causeway sections, which are standard for Seabee-supported amphibious operations, were used as barges for the original movement of material and personnel from the Landing Ship Dock to the shore and then were formed into the floating pier.

The primary facilities for directly supporting the aquanauts and the project mission were located in Beehive Cove as shown in Fig. B1. The support barge consisted of an Ammi pontoon upon which the communication and scientific-data-collection systems and the breathing-gas and utility-supply systems were assembled by Seabee personnel. The communication and data-monitoring systems were preassembled in a trailer van (surface control center van) by General Electric under project management by and contract with ONR. The support barge was located adjacent to the shore and hoisted out of the water on pile legs. Electrical power, generated and transformed on the support barge, was conducted to the habitat by a 1000-foot armored submarine cable. Breathing gases and potable water were carried to the habitat by hoses. Communication and data signals were transmitted between the support barge and habitat by another 1000-foot armored submarine cable. All umbilicals were designed and manufactured or procured by General Electric and were installed by the Seabees.

The habitat provided the hotel and laboratory facilities for supporting the life and work of the aquanauts. It was designed and fabricated by General Electric and was assembled by personnel from General Electric and the Philadelphia Naval Shipyard, all under ONR project management.

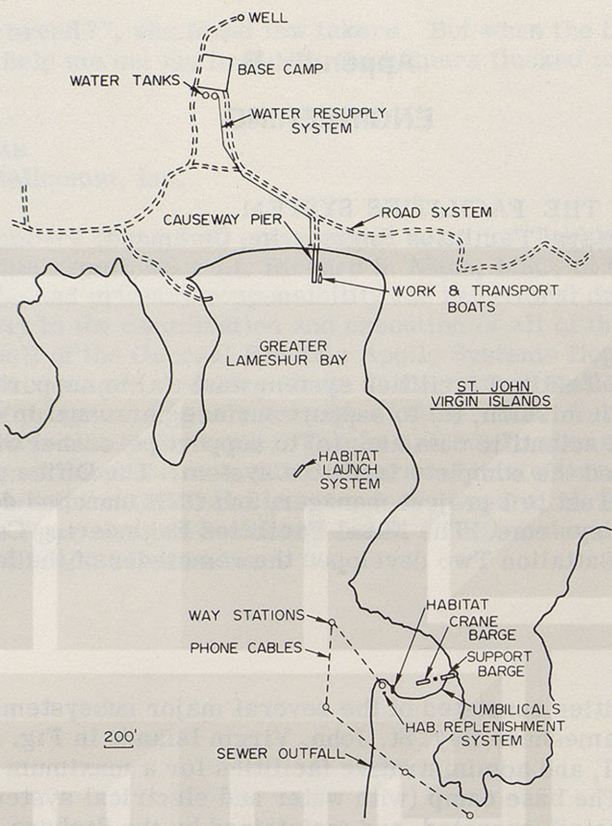


Fig. B1 - The Tektite I facilities system

Ranging out from the habitat and interconnected by sound-powered phones were five way-stations, designed and fabricated by General Electric under ONR contract. The way stations (Fig. B2) consisted of a Plexiglas, hemispherical shell mounted on a cylindrical steel cage. The base of the cage was a steel plate 1/2 inch thick and 5 feet square, the weight of which prevented the assembly from rising to the surface when the plastic dome was filled with air from a scuba bottle located in the way station. A valve on the top of the dome vented out the air after each use. The way station provided a means for the aquanauts to gain protection from a possible predator attack and to communicate with aquanauts in the habitat or in another way station through the sound-powered phones.

To resupply the habitat with such items as food and CO_2 absorbent and to dispose of garbage, pressure- and waterproof canisters were provided, the largest of which was capable of moving 300 pounds between the surface and the habitat (Fig. B3). The largest canister was designed and fabricated by General Electric under ONR contract. The Seabees fabricated a platform float with a center well from 55-gallon fuel drums and planking, and anchored it near the habitat. It was provided with an A-frame and hand winch to lower the canisters to the bottom near the habitat entrance. Air-inflated lift bags were used to swim the heavier canisters to a position under the habitat access trunk. An electric hoist in the habitat was used to raise the canister into the dry space for loading and unloading.

Extending seaward from the habitat was a 1000-foot sewer outfall. It carried mascerated, chemically treated sewage to a point where ocean currents would disperse it, thereby eliminating shark attraction and biotic contamination from the region around the habitat.

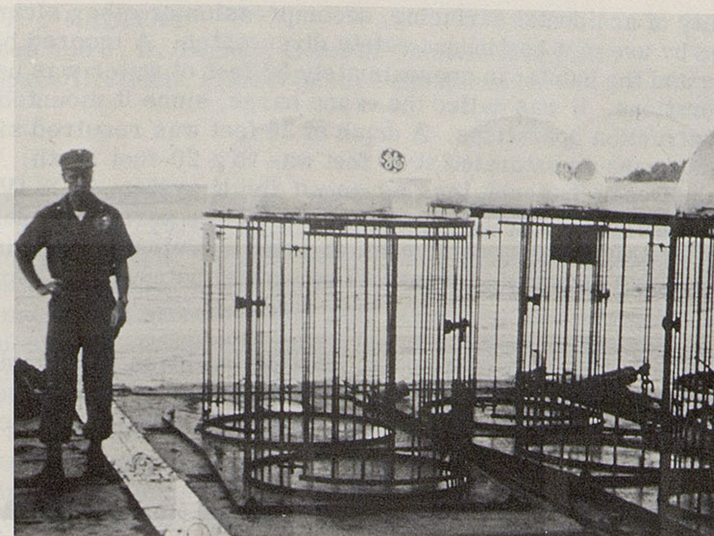


Fig. B2 - Way stations prior to outfitting with scuba tanks and sound-powered phones

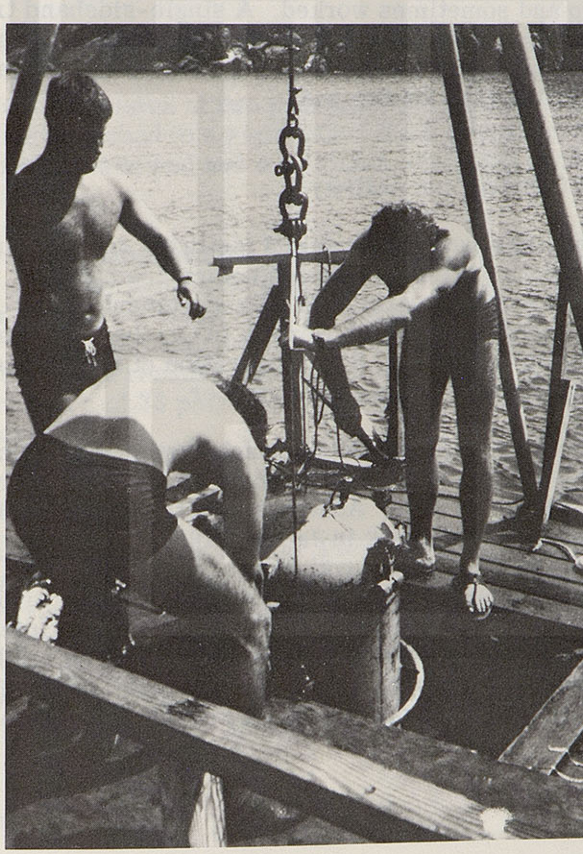


Fig. B3 - Canister for dry transfer between the surface and the habitat

The possibility of accidental surfacing, decompression or other sickness, or drowning was countered by use of a continuous safety diver watch. A moored barge between the support barge and the habitat in approximately 26 feet of water was used as a base for the safety operations. It was called the crane barge, since it mounted a 35-ton mobile crane used in construction operations. A depth of 26 feet was required since the upward excusion limit for aquanauts saturated at 43 feet was to a 20-foot depth. The safety center consisted of the Ocean Systems, Inc., advanced diving system (ADS IV, provided under the Supervisor of Salvage contract), the crane to handle the personnel transfer capsule, storage facilities for safety diving equipment, and small boats to carry divers to the rescue site. A float was provided to transport personnel between the support barge and the crane barge.

The habitat and all other undersea and supporting facilities were installed and integrated by Seabee construction divers and Seabee surface operations personnel. All construction operations were performed by Seabee personnel under the direction of the Naval Facilities Engineering Command.

A radio communication system was provided. It consisted of AN/PRC-47 sets in the support van, the base camp, the Coast Guard station on St. Thomas Island, and personnel boats used for interisland transportation. As an auxiliary system, Motorola PT/200 hand sets were located in the support van, the base camp, the crane barge, the diving barge, and the safety diving boats. A commercial marine radio-telephone set was provided in the support van. Commercial telephones, with access to the U.S. mainland, were provided in the base camp and sometimes worked. A single-sideband transceiver was provided in the base camp for intermittent communications with ONR in Washington, D.C. Emergency evacuation could be accomplished by a Navy or Coast Guard helicopter, with the causeway pier serving as the landing pad.

B1.3 Engineering and Construction Activity

Site surveys to provide a basis for detailed facilities design were completed in early September 1968, at which time facilities design commenced, except that the detailed design of the habitat was initiated in early 1968. Procurement of materials and prefabrication of the base camp was completed in Norfolk in October 1968, and on-site construction was completed by late November. Site preparation of the habitat and launch sites was completed by the advance party late in November.

Operational test of the prototype habitat launch system was completed in late October. The undersea construction systems, including the habitat launch system, were essentially completed in late December. Assembly and testing of the habitat and support barge were completed by the first week in January 1969. The landing ship dock, *USS Hermitage*, departed the Philadelphia Naval Shipyard with all facilities components, construction systems, and personnel on January 8 as scheduled. It arrived in Lameshure Bay, St. John Island, the morning of January 12, 1969, at which time off-loading commenced. Construction activity commenced on January 13. The facilities construction was essentially completed and the facilities system checked out by February 13 to permit commencement of the Tektite I operations on February 15 as scheduled.

B2 THE TEKTITE I HABITAT

B. P. Thompson and J. B. Tenney, General Electric Company,
Missile and Space Division, Philadelphia, Pennsylvania

B2.1 Design

The design for the Tektite I habitat was the responsibility of the General Electric Missile and Space Division, Philadelphia, Pennsylvania. This task was begun in January 1968 and was completed except for necessary liaison and engineering development tests by July 1968. For convenience in design the system was considered to consist of seven major subsystems: habitat structure and base structure, environmental control subsystem, electrical subsystem, water and sanitation subsystem, communications subsystem, atmospheric monitoring subsystem, and interior and furnishings.

In each area a responsible subsystem engineer was responsible for design, specification writing, hardware selection, component and subsystem testing, and subsystem startup in the field. This emphasis on total responsibility assured continuity of effort and was responsible in part for the successful performance of the habitat in the field. Each engineer was responsible for performing all component and subsystems tests necessary to verify adequacy of design.

B2.2 Structure

B2.2.1 Pressure Hulls

The habitat structure consisted of two pressure hulls interconnected by a pressurized crossover tunnel and attached to a rigid base. Each pressure vessel was a vertical cylinder with torispherical heads and had a maximum diameter of 12.5 feet and a maximum height of 18 feet.

The pressure hulls were designed for pressurization on the surface to a level equal to the water pressure at the emplacement depth. The 1/2-inch-thick welded SA285-Grade C steel hull was designed in accordance with the requirements for an internally pressurized, unfired pressure vessel as described in Section VIII of the ASME Boiler and Pressure Vessel Code for Unfired Pressure Vessels. Hull structures were designed for a maximum operating pressure of 33 psig and hydrostatically tested to 50 psig, or 1.5 times operating pressure.

B2.2.2 Viewing Ports

The habitat contained six 2-foot-diameter Plexiglas hemispherical windows located around the habitat to provide nearly full 360-degree visual coverage. The hemispherical windows were for observational use for scientific, recreational, and diver safety purposes. Hemispherical windows in addition to being structurally efficient provided a wide field of view and a normal image which was neither greatly magnified nor distorted. Each window was proof tested at 50 psig. An observation cupola atop the equipment room had eight flat-plate, Plexiglas windows around its circumference providing a full 360-degree visibility.

B2.2.3 Access Openings

Normal entry into the habitat was provided by an open 4-foot-diameter entry trunk in the wet room. A normally closed 3-foot-diameter hatch in the crew quarters was provided for emergency underwater egress.

B2.2.4 Shark Cage

At the main entry into the wet room a screened shark barrier and door were provided. This cage permitted the aquanauts to leave the base and survey the surrounding area without exposure to attack by predators.

B2.2.5 Service Penetrations

Service penetrations for feeding in the electrical, water, communication, and air umbilicals were made in a removable plate bolted to a trunk in the lower head of the wet room. All other hull penetrations were located low in the hull to minimize loss of atmosphere and flooding in the event of external line damage. Each hull penetration was equipped with a manual shutoff valve inside the habitat.

B2.2.6 Support Structure and Base

Each pressure hull had three support legs which bolted directly to the habitat base structure. The base was a welded steel reinforced rectangular box weighing 68,000 pounds with approximate dimensions of 15 by 34 by 6 feet serving as a structural interconnection of the two pressure vessels, a mounting platform for fixed and variable ballast, a mounting base for ancillary equipment such as emergency air bottles, and a passageway for diver entry and egress.

B2.2.7 Ballast Tanks

Incorporated in the base were buoyancy tanks which allowed adjustment of overall system buoyancy from a positive 5000 pounds to a negative 5000 pounds. Fixed ballast in the form of 133,000 pounds of scrap steel punchings was located in the base. The base was designed to be placed directly on the leveled ocean bottom and securely moored to clump anchors. Winches mounted on the base pulled it down to the anchors under a 5000-pound positive buoyancy. After the base was secured, the buoyancy tanks were flooded to add to the overall negative buoyancy. A total net negative buoyancy of 20,000 pounds on the bottom assured stability in any normal sea conditions at the site. Ancillary equipment mounted on the base included air storage bottles, external storage racks, towing bitts, chocks, and cleats.

B2.2.8 Crossover Tunnel

The tunnel connecting the habitat cylinders was a standard industrial expansion gasket designed for long service at temperatures and pressures in excess of the Tektite I service environment. The unit selected was designed for service at an internal pressure of 33 psi.

B2.3 Equipment

B2.3.1 Introduction

Mechanical equipment and components selected for use in the Tektite I habitat were of commercial quality. Each component was carefully evaluated by the engineer responsible for its selection to determine its suitability. In cases where the ability to perform under pressure was questionable the component was tested prior to the start of the mission. Very few equipment items required modifications as a result of increased pressure. Control devices on both the refrigerator and the freezer were modified.

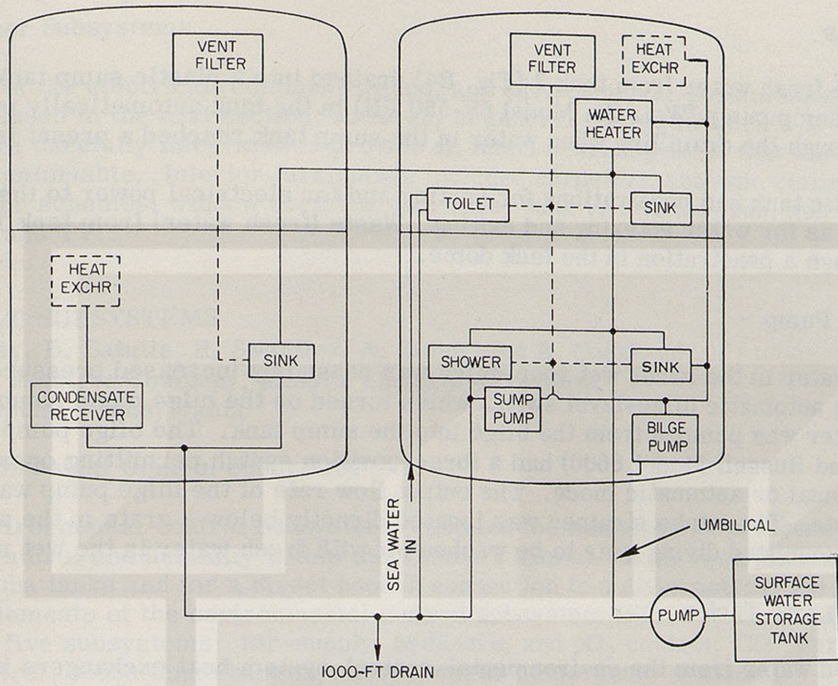


Fig. B4 - The plumbing system, which transmitted fresh, potable water from the surface and provided sea water for operation of the waste disposal facilities

The plumbing system (Fig. B4) transmitted fresh, potable water from the 3000-gallon pillow tank aboard the habitat support barge, provided personal hygiene facilities, and provided a drain hose for waste disposal. It also provided sea water to operate the toilet.

B2.3.2 Fresh Water Supply

Fresh water entered the habitat through a penetration in the umbilical plate (wet room). Water from the storage tank on the control barge provided water at 100 psig to meet a maximum habitat demand of 10 gallons per minute and a total maximum usage of 280 gallons per day. The supply umbilical was clear, 3/4-inch nylon-braid-reinforced PVC flexible hose with a minimum working pressure of 125 psi. Two-way-shutoff quick-connecting fittings were installed on each end of the 1000-foot umbilical. A hose bib allowed connection of a 25-foot garden hose in the wet room.

B2.3.3 Hot-Water Heater

Hot water was provided by a fully automatic 80-gallon heater (General Electric Model WRW4 82). The automatic thermostat was adjustable from 120°F to 170°F and was nominally set at 150°F.

B2.3.4 Sinks

The Tektite habitat was provided with three sinks. In the crew quarters the sink in the galley area was a stainless steel basin in a Textolite countertop. In the engine room a stainless steel basin was provided adjacent to the toilet area. In the wet room a large single-basin stainless steel sink was built into a stainless steel counter top for use in scientific work.

B2.3.5 Drains

All waste fresh water from tank 2 (Fig. B4) drained into a plastic sump tank under the floor. A sump pump (Weil Co. Model SS-550 PH) in the tank automatically pumped water out through the drain line when water in the sump tank reached a preset level.

The plastic tank had penetrations for venting and for electrical power to the sump pump as well as for water entering and exiting. Waste (fresh water) from tank 1 drained directly through a penetration in the tank dome.

B2.3.6 Bilge Pump

Rise of water in the lower wet room bilge was sensed by increased pressure in the air bell of the automatic bilge-level switch which turned on the bilge pump mounted under the sink. Water was pumped from the bilge into the sump tank. The bilge pump and motor (Peters and Russell Model 6600) had a three-position switch permitting operation in either the manual or automatic mode. The output flow rate of the bilge pump was 9 gallons per minute. The intake strainer was located directly below a grate in the wet room floor, which permitted diving gear to be washed off with fresh water in the wet room.

B2.3.7 Condensate Tank

Condensed water from the environmental-control-system heat exchangers in tank 1 flowed into a small receiver tank. A pump unit (Hartell Centiflo Model A-1) rated at 2 gallons per hour (10-ft head) pumped condensate through a check valve and into the fresh-water drain line. In tank 2 condensate drained directly into the sump tank.

B2.3.8 Vent Lines

All internal plumbing lines were vented inside the habitat into charcoal filters (Mine Safety Appliance Type N, Model SW), which eliminated many vent gas odors.

B2.3.9 Toilet

A crown head marine toilet (Raritan Deep Draft Model, 110-120 volts, 60-Hz ac, single phase) was located in the engine room. This toilet used sea water and was equipped with a macerater and a chlorinator.

B2.3.10 Shower

A stall-type shower in the wet room was used to warm divers after each excursion. The shower drained into the plastic sump tank.

B2.3.11 Refrigerator-Freezer

A refrigerator-freezer (General Electric Model CAF-13CD) with a capacity of approximately 13 cubic feet was located in the crew quarters. For storage of frozen food and specimens such as blood and urine an upright freezer (General Electric Model TBF-12DD) with a capacity of approximately 12 cubic feet was located in the engine room. Control elements of both units required slight modifications to operate at increased pressure.

B2.3.12 Oven-Range

An electric oven-range in the crew quarters had four surface elements.

B2.3.13 Other Subsystems

Details of the electrical, communications, and environmental-control subsystems will be discussed in the next section; however, in general the requirements of these subsystems were carefully integrated to provide an interior arrangement that was both functional and comfortable. Interior furnishings included carpeting, acoustic ceiling tile, selected color schemes, window curtains, individual bunk ventilation fans, and recreational radio and TV.

B3 HABITAT SUBSYSTEMS

D. Withey, B. Batutis, R. Swartley, A. Quinn, and R. Cockfield,
General Electric Company, Missile and Space Division,
Philadelphia, Pennsylvania

B3.1 Environmental Control Subsystem

The environmental control subsystem regulated the atmospheric pressure, composition, temperature, and humidity within the Tektite I habitat. It also provided air for charging scuba tanks and for a direct hookah connection to a diver outside the habitat. The basic elements of the environmental control subsystem (Fig. B5) were functionally divided into five subsystems: air-supply, pressure, and pO_2 control; CO_2 scrubber; thermal control; scuba tank charging subsystem; and emergency systems.

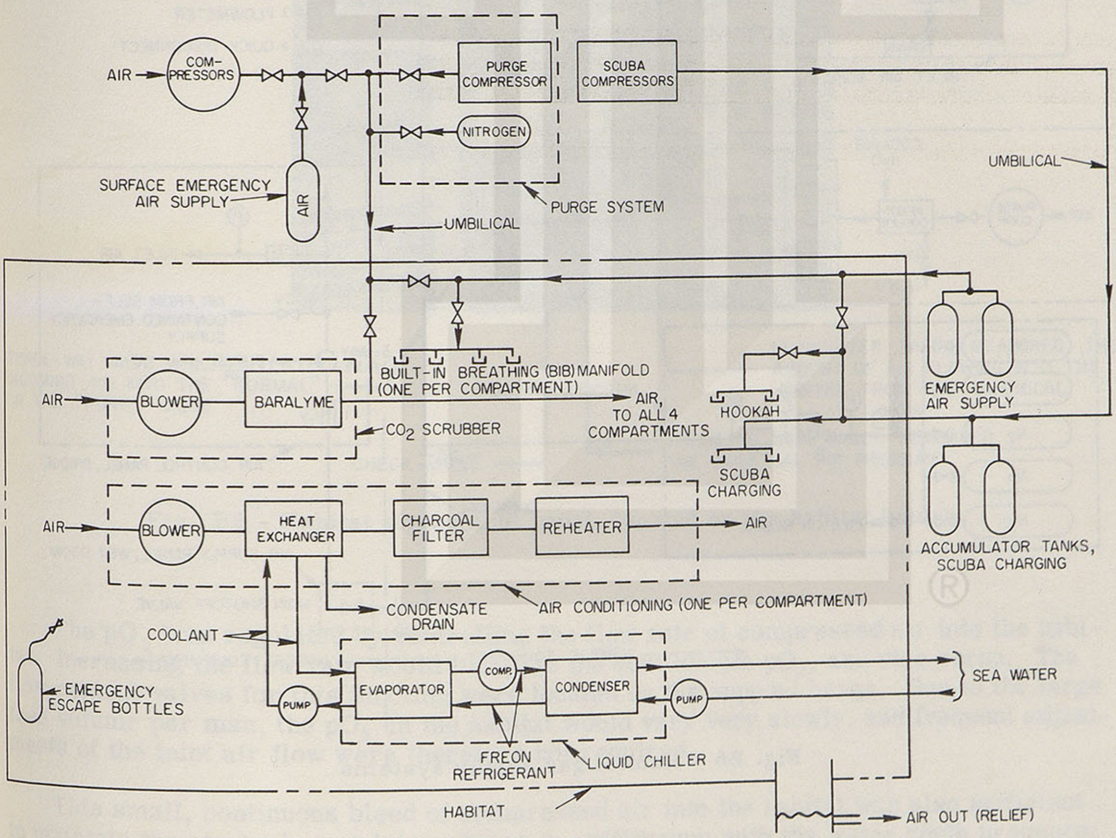


Fig. B5 - Basic elements of the environmental control subsystem

B3.1.1 Air Supply, Pressure, and pO_2 Control

The habitat was initially pressurized on the surface with air to the emplacement depth pressure. After emplacement and prior to the start of the mission the atmosphere was diluted with nitrogen to reduce the oxygen partial pressure (pO_2) to 160 torr. This nominal level was maintained throughout the mission by continuously bleeding compressed air to the habitat via an umbilical from one of two air compressors at the surface support barge. Figure B6 shows the schematic for the gas supply systems, Fig. B7 shows the main air control valve in the wet room, and Fig. B8 shows the control panel in the bridge where the inlet air flow was monitored by the aquanauts. The pO_2 limits established for the mission were 151 torr to 165 torr. These extremes allowed the aquanauts external excrusion to the maximum height above their saturation depth while maintaining the controlled atmosphere required for biomedical studies.

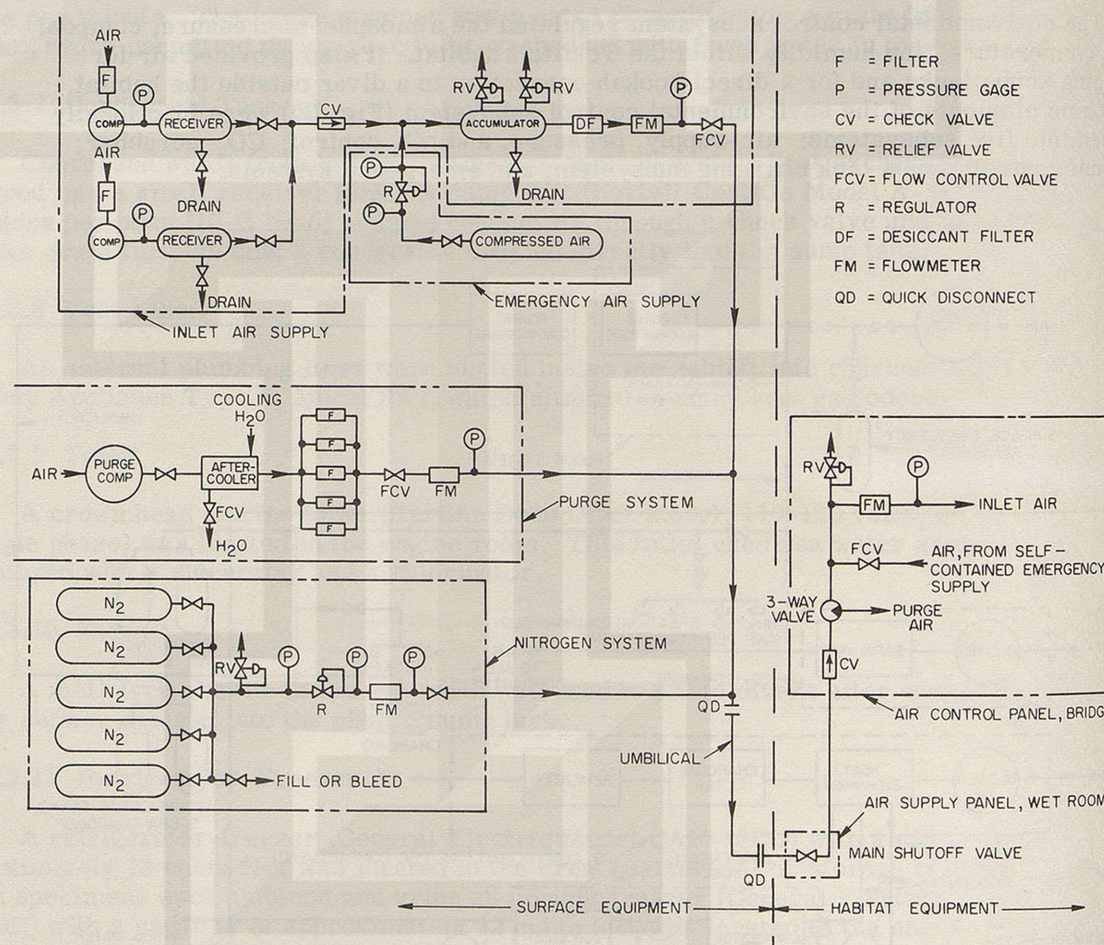


Fig. B6 - Habitat gas supply systems

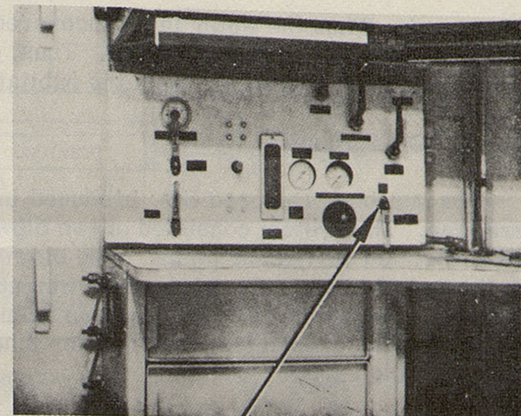


Fig. B7 - Habitat air supply panel, located in the habitat wet room. The valve shown is the main air shutoff valve for the entire habitat.

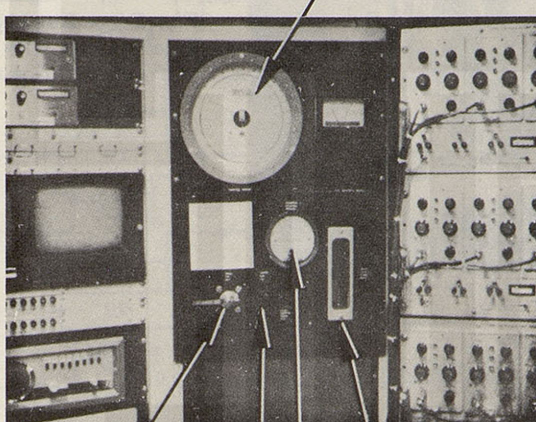


Fig. B8 - Habitat air control panel, located on the habitat bridge

The pO_2 was regulated by controlling the flow rate of compressed air into the habitat. Increasing the flow rate would increase the equilibrium pO_2, and vice versa. The flow control valves for this function were located on the support barge. Due to the large free volume per man, the pO_2 in the habitat would vary very slowly, and frequent adjustments of the inlet air flow were therefore not required.

This small, continuous bleed of compressed air into the habitat was also sufficient to maintain the atmosphere total pressure in equilibrium with the water depth pressure; i.e., as the tide or barametric pressure increased, the habitat pressure also increased due to the addition of inlet air. Pressure relief was provided by three side ports in the entry trunk. When the water level uncovered these ports due to increasing habitat pressure, excess air simply bubbled out. Thus, during the mission there was a small relatively continuous flow of air from the habitat.

B3.1.2 CO_2 Scrubber

The scrubber removed CO_2 produced in the habitat by chemical absorption with baralyme. The system consisted of two blowers (one redundant), a baralyme canister, and associated valves and piping. The blower provided forced circulation of the habitat air through the baralyme, where CO_2 was absorbed. The processed air was then directed in equal parts to each of the four compartments. The baralyme canister (Fig. B9) was sized to hold sufficient chemical for 8 hours of use, after which time it would require replenishment.

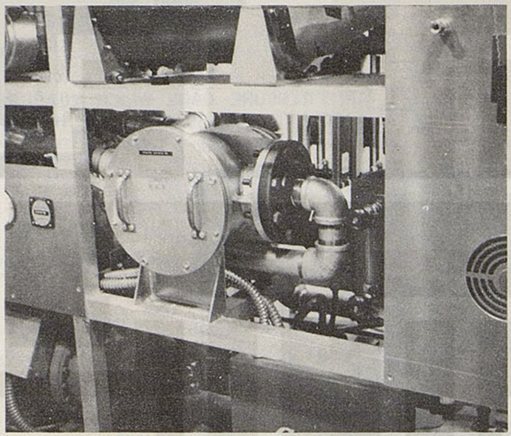
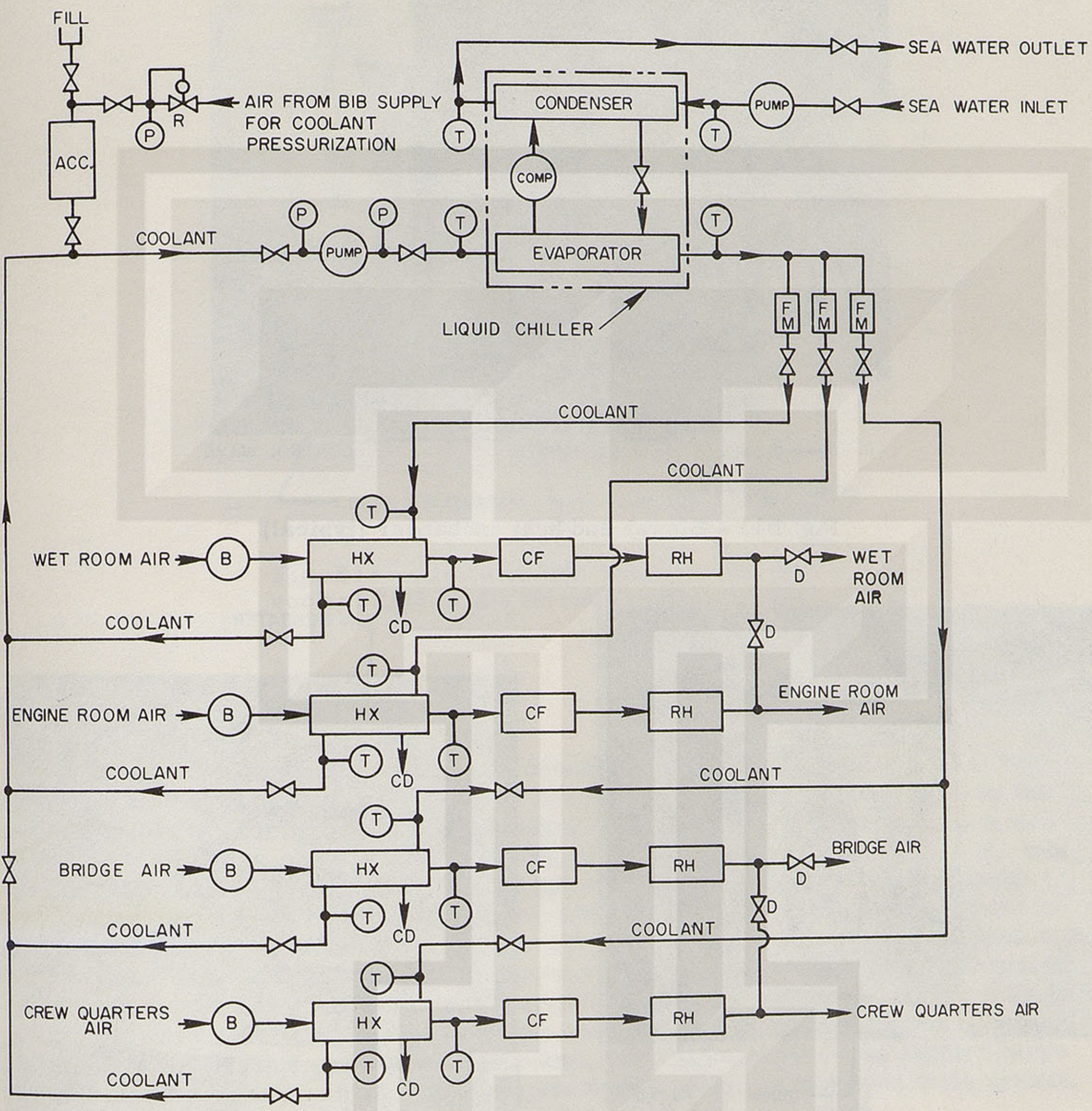


Fig. B9 - Baralyme canister, located in the mechanical equipment room

B3.1.3 Thermal Control

The thermal control system shown schematically in Fig. B10 regulated the habitat air temperature and relative humidity. Since the water temperature surrounding the habitat was 77 to 78°F, the walls of the habitat were essentially adiabatic; that is, heat loss to the water was negligible. Thus heat generated by the men and equipment had to be removed by an active cooling system. A cabin heat exchanger served each compartment, although the output of the two heat exchangers in each cylinder were connected so that additional capacity could be obtained for the peak loads. Each heat exchanger loop included a blower for air circulation, a charcoal filter for odor and trace contaminant control, and an electrical heater (Figs. B11 and B12). The blower forced air over cold coils in the heat exchanger, removing sensible heat; excess water vapor condensed on the coil surface, removing latent heat (dehumidification). The cool dehumidified air then passed through the reheater (Fig. B13), where the air temperature was increased depending on the desired room air temperature and the internal heat generation rate. Therefore, this system provided dehumidification of the air, even during periods of low sensible heat load. During periods of high internal heat generation, little or no reheat of the air was necessary. Low heat generation conditions, however, required the maximum reheater power to maintain comfortable air temperatures. The power applied to the reheaters was controlled by room air thermostats, which allowed selection of air temperatures between 75 and 90°F.



LEGEND:

P = PRESSURE GAGE

T = TEMPERATURE GAGE

R = REGULATOR

ACC. = ACCUMULATOR

FM = FLOWMETER

B = BLOWER

HX = HEAT EXCHANGER

CF = CHARCOAL FILTER

RH = REHEATER

D = DAMPER

CD = CONDENSATE DRAIN

Fig. B10 - Thermal control system

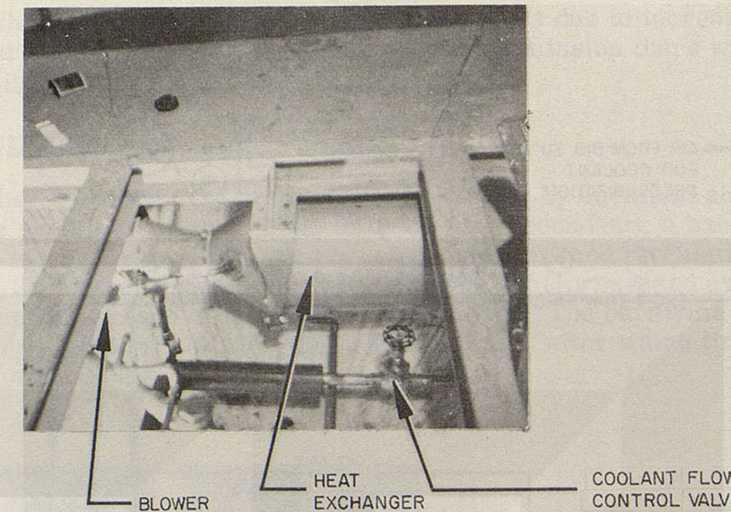


Fig. B11 - Blower and heat exchanger (typical)

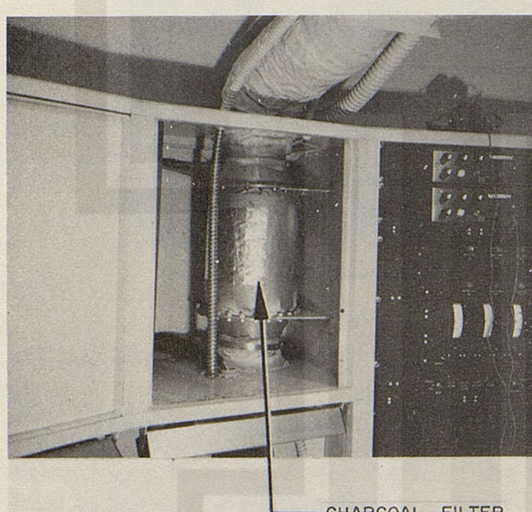


Fig. B12 - Charcoal filter (typical)

Fig. B13 - Reheater which heated dehumidified air to the desired room temperature

Coolant for the heat exchangers was supplied by a liquid chiller in the engine room (Fig. B14). Associated pump, valves, flowmeters, piping, etc., circulated 30% glycol/water coolant to the four heat exchangers and return. The liquid chiller itself was a conventional Freon compressor refrigeration unit, with modifications to the controls to allow operation at the high ambient pressure. Ultimate heat rejection from the system was to the sea water via the sea-water condenser on the refrigerator unit.