Eight lobsters were tagged with sonic pingers by the aquanauts. Two of these eight were never relocated. One lobster was relocated periodically over a 24-day period; the remaining five were relocated periodically over periods of 2 to 10 days.

A1.2.3 Observations on Diurnal Behavior

Spiny lobsters normally spend the daylight hours on the reef in a den. The lobsters observed during this study showed definite preferences for particular areas on the reef and for particular dens. In the two sections studied by the aquanauts (sections 8 and 9 in Fig. A1) no lobsters were ever found in the patch reef area northeast of the habitat. Within the reef area south of the habitat 17 lobster dens were found. Nine of these dens frequently contained two or more lobsters; the largest group found in one den was 20. The eight remaining dens would accommodate only one lobster. The lobsters found in these dens were usually large males or females with eggs. Although certain caves and holes were preferred by the lobsters, the aquanauts could not describe why they were selected instead of others.

It is generally accepted that by staying in a den during the daylight hours the lobster will be protected from predators. The lobsters observed usually had their entire body hidden from view, but had their antennae projecting out through the opening of the den. As an aquanaut approached, they would generally point their antennae toward him and try to whip him with them. If he approached slowly, the larger males would frequently come out of the den toward him in a threatening manner; however, if he approached more rapidly, they would retreat, always keeping the antennae pointed toward him. If he put a hand into the den, the lobster would try to catch it between the antennae and hold it. Occasionally when the lobster had a hand between the antennae, it would push or jump forward and drive the spines that ring the antennae into the hand. If the aquanaut continued to threaten the lobster, it would push up with its legs and press the spines on its back into the roof of the cave, thus firmly anchoring himself inside. Once in this position it was not possible to pull the lobster out of the den without damaging it. Lindberg* has noted that a denned lobster would come out of its den and move to another den soon after the antagonist had left. The aquanauts also saw this happen on one or two occasions.

When a cave or hole contains lobsters, it is seldom inhabitated by any other large animals. Although almost every niche contained spiny sea urchins, they were seldom found in a den occupied by lobsters. The aquanauts did not see lobsters actively removing sea urchins from a den or preventing them from entering. Their studies show that the lobsters move into the dens well before the first light of morning; this may result in their occupying the dens first. If so, it would be quite easy for them to keep the spiny sea urchins out by using their antennae. The aquanauts observed fish trying to enter occupied dens on various occasions, and the fish were always repelled. The lobsters were extremely aggressive toward the fish, lashing them with their antennae. Lobsters and fish, including moray eels, were never seen occupying the same den.

Most of the lobster dens south of the habitat were so limited in size, particularly in the vertical dimension, that a large predator such as a grouper or shark would be unable to enter the den; however, off the tip of Cabritte Horn Point (near the boundary of sections 9 and 10) a group of large lobsters were discovered living under ledges several feet long, two of them 3 feet deep and one 2 feet deep. Shortly after the aquanauts discovered this population, a group of seven nurse sharks, 8 to 12 feet long, moved into the area and occupied these ledges along with the lobsters. Even after the sharks had been in the area

*Robert G. Lindberg, "Growth, Population Dynamics, and Field Behavior in the Spiny Lobster, Panulirus interruptus (Randall)," Univ. of Calif. publication Zool. 59(6), 157-248 (1955).

over 24 hours, the lobsters were still remaining under these ledges. Three days later the sharks had left and no lobsters were in the area. None of the three lobsters of this group that had been sphyrion tagged were ever resighted. The act of entering a confined area during the daylight hours certainly must have survival value, but the factors that stimulate the lobsters to respond in this way must be quite variable or this group of lobsters would not have selected such open ledges (unless there were no other dens available). No effort was made to observe these lobsters at night, but if they left their dens, the sharks probably could have caught them quite easily.

The question of what causes the lobsters to select particular dens and particular areas of the reef warrants study. Few lobsters were found living in complete isolation; even those that occupied solitary dens, including berried females, usually were within a few feet of other lobsters.

Very few small lobsters were found on the reef, and those were in very shallow water. However, several small lobsters were seen living within a colony of spiny sea urchins out on the sand-algal plains. This commensal relationship, observed several times, apparently affords the young lobster a mobile shield from predators, with the shield continuously moving onto new feeding grounds. When these lobsters were removed from the colony and released, they immediately returned to the colony. The dark purple spiny sea urchin colony is easily seen on the gray sand-algal plains, and it must provide a strong visual stimulus to the small lobster. The ecology of this association should be studied to determine if immature lobsters seek these colonies as their first home on the bottom and to determine what stimulates them to enter the colony.

Soon after the sun sets, the lobsters begin to move out into the entrances of their dens. They are sometimes very aggressive during this time of day and may come out of the den waving their antennae toward an approaching diver. As the diver comes in closer, the lobster will begin to back up and seek refuge. Many times they will move across the reef to a new shelter instead of returning to their former den. Although the lobsters appeared to be more active during this period, they did not move out onto the sand-algal plains until 2 or 3 hours after sunset. The lobster is capable of walking very fast across the plains and were found moving as far as 300 feet from the reef. One walked over 800 feet in 3 hours and 45 minutes. Observations of lobsters feeding on the plains were not made, but feeding is assumed the primary reason for their migration into that area. While the lobster is out on the plains, it does not display the aggressive behavior it does on the reef. When approached it either walks away very fast or stops and lays its antennae over its body and remains very still. This response to divers, working without lights, indicates it would be extremely easy for a predator to catch a lobster once it had found it. One of the pinger-tagged lobsters was killed and eaten out on the plains. Its carapace was crushed and the majority of the tissue was removed from the cephlothonax and abdomen, but neither the skeletal parts of the legs nor the abdomen were badly damaged.

The lobster's migration out onto the plains and his subsequent return to the reef seem to be well-directed movements. One female carrying eggs was followed as she returned to the reef about 4:30 a.m. Her walking carried her around the tip of the reef west of the habitat and directly to a den 225 feet east of the habitat. The following morning this same lobster was found returning to the same den along the same route. This incident along with several others observed during the 60-day period indicates the lobster has a well-developed navigational ability.

A1.2.4 Range of Lobsters during the 60-Day Period

Two methods of describing the range of the lobsters was attempted during the 60-day mission; one was to plot the movement of sphyrion-tagged lobsters using the resighting data. Of the 137 lobsters tagged, 42 were resighted. Only four of these were found in a section other than the one they were tagged in, and none of them had moved more than 1500 feet from the place they were initially tagged.

The second method of determining the range and possible migration was the tracking of the lobsters tagged with sonic pingers. None of these lobsters were found to move out of the sections they were tagged in, and generally stayed within a few hundred feet of the place they were found initially.

Both of these methods indicate the lobsters stayed within a limited area of the reef during this 60-day period; however, our inability to locate more of the sphyrion-tagged lobsters and the loss of two of the lobsters tagged with sonic pingers leaves this statement open to question.

A1.2.5 Molting and Reproduction

Seebee divers reported seeing many lobsters cut in half and lying on the bottom during the period they were emplacing the habitat. Upon examination, however, these were found to be exuviae. The aquanauts continued to find recently cast exuviae during the first half of the mission, but no exuviae were found in the latter half. Only one soft-shelled lobster was found during the dive. Most of the lobsters found during the first part of the mission had very clean exoskeletons. Toward the end of the 60 days some lobsters were found with encrusting organisms growing on them, particularly on the carapace close to the base of the fifth legs.

Thirteen of the 57 females tagged with sphyrion tags had eggs; an additional ten had been plastered with sperm. Twenty-two had short eroded setae, which indicates they would not be receptive to breeding. Although an increase in the percentage of berried females was expected as the 60-day period progressed, the data did not indicate this. One reason may be the tendency of the berried female to isolate herself in a well-concealed burrow. One lobster that was tagged with a sonic pinger when carrying sperm deposited eggs a few days later and moved inshore to a well-concealed burrow; without the sonic tag the aquanauts would not have relocated her. Another berried lobster carrying a sonic tag also moved inshore shortly after being tagged. Because of the 20-foot upward depth limit the aquanauts were not able to follow this animal.

A1.2.6 Population Estimation

During the Tektite I mission the aquanauts attempted to estimate the lobster population in eight of the 12 study sections by surveying transects. The number of lobsters counted, both tagged and untagged, was small. No conclusions have been drawn from these data, but it is doubtful that this is a satisfactory method to use in future studies of this type unless more and longer transects are used. This method along with two other methods that should be considered for future studies are described in the following paragraphs.

Before the transects were laid out, each section was inspected, and the different types (sand-algal plains, patch reef, coral reef, rock reef, and thallassia) were described. Transects 300 feet long were then laid out in the different types by placing two anchors on the bottom at each end of the transect and stretching a polypropylene line between them. All the area within 20 feet of this line was inspected each time the transect was surveyed. To help the surveyor keep within the prescribed width, a 20-foot line that had one end attached to a sliding ring on the transect line was carried by the surveyor. Theoretically this kept him within 20 feet of a straight line between the two anchors, but it was found that the surveyor might pull on this rope, thus pulling the transect line off center, and survey a larger area than intended.

Transect surveys are used frequently as a method of estimating populations, and the statistical methods for analysis are available. In spite of this advantage it appears that this method will not be satisfactory for lobster surveys unless a much larger area is surveyed.

Another method of estimating the population may be to search an entire section and record tagged and untagged individuals. On April 12 the four aquanauts spent the day searching the reef from the habitat, south 700 feet, and from the 20-foot depth contour to the western margin of the reef. A total of 38 lobsters, including 14 tagged individuals, were found. By scheduling a series of tagging dives with a survey of this type following each one, a satisfactory number of individuals would be counted to make a good population estimate.

A third method of estimating the population may be built around the habit of lobsters selecting particular dens on the reef. Of the 38 lobsters found on the April 12 survey 25 were in previously recognized dens. The advantage of a method like this would be the short time it takes to inspect a series of known dens on a reef as opposed to searching the entire reef. On the reef area mentioned it takes about 1-1/2 swimmer-hours to inspect all the dens identified. The search of the entire area took 14 swimmer-hours. The disadvantage of this method is that the berried females and some solitary males may avoid these dens and therefore be excluded from the estimate. This method as well as the first two would exclude from the estimate the immature individuals living in the spiny sea urchin colony.

Before a comprehensive method of estimating the population of lobsters can be developed, it is necessary to describe the behavior of the animal from the time he settles to the bottom to adulthood. Because of the many different niches the lobster occupies during its life cycle, it may be necessary to develop different techniques of population estimation for each mode.

A1.3 Cleaner Shrimp Ecology and Plankton Studies

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A1.3.1 Cleaner Shrimp Ecology

An interesting symbiotic cleaning behavior exists between certain brightly colored shrimp and cooperating reef fishes. The shrimp, which are almost invariably associated with an anemone, have been observed to pick and eat parasites, injured tissue, and other undesirable particles from a large variety of reef fishes and probably are the primary agent in the control of gill, oral, and external parasites. This seemingly unusual activity may play a major role in maintaining local concentrations of many species of reef and pelagic fishes. Indeed, the abundance of such fishes may be directly related to the abundance of the anemone, *Bartholomea annulata*, to which cling the two most abundant cleaners, the Pederson cleaning shrimp *Periclimenes pedersoni* and the spotted cleaning shrimp *P. yucatanicus*.

Ecological studies were carried out during Tektite I on the distribution of cleaner shrimp and anemones with relation to various reef environments. To this end, five topographic features on the reef and sand flats south of the habitat were chosen as representing the major ecological zones. Anemones and shrimp were completely enumerated within each zone at least once during the study. In addition, shrimp populations on 26 anemones in the sand strip at the reef base were monitored each week. The shrimp were found to be rather fearless and could easily be enticed to browse along the back of a diver's hand, where they assiduously picked at hairs. It therefore became a matter of routine for a diver to measure the length of living shrimp either on the anemone or on the back of his hand.

It was found that the anemones were equally abundant in all five of the habitat types, but the abundance of shrimp varied. *P. pedersoni* was most abundant along the sand strip, an area at the reef base grazed clean of algae by fishes to about 10 meters from the cover of the reef. The sand strip is the major corridor for fish movement along the reef and therefore supports larger numbers of cleaning stations. One of the most frequented stations contained 26 *P. pedersoni*. *P. yucatanicus* on the other hand was most abundant on the sand flat beyond the limit of grazing, an area of scattered coral rubble and heavy algal growth.

Additional observations were made on precleaning behavior, intraspecific size dominance, interspecific competition, shrimp-host anemone dependence, shrimp repopulation studies, and the relationship between anemones and other caridean associates. One specie, and possibly two species, of *Periclimenes* collected from anemones during Tektite I may be new to science.

A1.3.2 Plankton Studies

Diel (24-hour) variations in the vertical distribution of zooplankton were studied with the aid of a plankton pump. A nonmetallic pump of 50-gal/min capacity was used to pump water from a vertical standpipe about 10 meters from the habitat. The base of the polyvinyl chloride standpipe was anchored to a 2500-pound cement clump, and the upper end was attached to a surface buoy. Hydraulic-pressure-operated valves were arranged along the pipe at ten depths and could be operated one at a time from the habitat. The pipe entered the habitat through a 10-inch floor trunk in the wet room, and water was pumped into a filtration barrel containing a set of nested nitex nets.

A1.4 Marine Geology

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The specific objectives for the marine geology program in Tektite I included: the evaluation of saturation diving and sea-floor habitation in geological research, compilation of a detailed map of the sea floor delineating the various types of substrate in the vicinity of the habitat, and research on specific geological problems as found feasible.

The area surrounding the habitat was mapped using large-scale colored aerial photographs and infrared images, which delineated the geometric relationships among the larger features such as sand flat, bedrock, bedrock rubble, coral reef, and major groove or canyon systems. Details were added underwater by tape and compass procedures or by sketching. The completed map provided a basis for further geologic investigations and for biologic research.

An interesting aspect of the sea-floor map is the presence of two sets of linear grooves (or canyons) through the coral reef proper. The most distinctive trends N25°E; the other set, which appears to be less well defined but consists of larger grooves, trends N45°E. Both sets presumably formed in response to the direction of wave approach but possibly at different times or under different conditions. Gorgonians (sea fans) and platy milliporids (fire coral) dominantly grow normal to the present-day average of wave approach. The orientation pattern of these organisms in and adjacent to the grooves trends about N15°E, suggesting that both sets of grooves may either be relic features formed when wave approach followed a different pattern or result from unusual large-scale wave conditions.

Other geological research dealt largely with the interaction of organisms with the bottom sediment. The Tektite I project afforded an excellent opportunity to study the modification of the sand floor by crawling and burrowing creatures in the absence of sand transport by waves or currents. Black sand (composed largely of the mineral magnetite) was artificially layered with light-colored indigenous carbonate sand, and the effect of organisms on the layering was observed daily or bi-daily by coring the layered sand. These observations revealed a rapid rate of bioturbation. The uppermost 5 mm of sand in some areas was totally reworked in 4 days. Manually constructed sand ripples 1.5 cm high and 15 cm long similar to those produced by waves on the sea floor were obliterated within a week. The rate of lateral transport of sediment by organic reworking was checked using fluorescent tracer sands. During the time span of the experiment lateral transport proved to be negligible. The burial of solid objects by undermining organisms was also noted. One of the metal plates defining a locational grid intersection was buried 2 to 3 cm during the course of Tektite I.

Examination of more than 2300 empty pelecypod valves showed marked tendency for the valves to lie concave-up on the sea floor (in contrast to the generally accepted notion in geology that concave-convex particles lie dominantly concave-down). The orientation pattern seemed largely independent of the nature of the substrate. The percentage of concave-up shells rose with increasing shell size. Under the influence of waves or currents this relationship is reversed, suggesting that determination of the shell orientation pattern in relation to shell size constitutes a useful tool for identifying ancient environments. In an experiment 200 valves of different sizes were placed concave-up in a small area and 200 matching valves were placed concave-down nearby. Over a period of 2 weeks bottom dwelling organisms rotated shells of all sizes, but turned more concave-up than concave-down. Predators of the pelecypods and attendant scavengers probably also contribute to the observed orientation.

A joint study by aquanauts Clifton and Mahnken provided data on the amount of fine calcium carbonate (aragonite needles) contributed to the sediment by the calcareous algae *Penicillus* and *Udotea*. Immature specimens of these algae were tagged with carbon-14 and harvested 24 days later to determine the volume added. In addition, repopulation rates were determined for a totally depopulated 2-square-meter area. These observations indicate that the abundant *Udotea* in particular has a very rapid growth rate and may contribute substantially to the carbonate sediment.

Other joint geological-biological investigations centered on the origin of the unvegetated strip of sand that borders the reefs and on the influence of the sand tilefish on the bottom sediment. Textural analysis showed the sand from most of the sandstrip contains less material finer than 0.062 mm than does the sand from the vegetated areas beyond the strip. This difference may be due to entrapment of fine material by the algae or grass or result from winnowing of the fine material from the strip by reef-based fish who stir the sand while feeding on small organisms in it. Sand at the very edge of the reef contains abundant fine material, which appears to be "dust" produced by organisms that feed in and on the reef coral. The absence of vegetation from the sand strip seems not to result from inhibition of plant growth caused by chemical or biological agents in the sand near the reef. Experiments indicated that algae seemed, if anything, to grow more rapidly when growing through a cover of fine material from the reef edge. To test the effect of grazing by herbivorous fish, mature *Udotea* was transplanted at 10 foot intervals across the sand strip. Half of each transplant was covered with transparent screening, and half was left unprotected. In a matter of hours the unprotected algae nearer the reef was devoured by parrot fish, and the unprotected algae at the outer edge of the strip disappeared within a few days. The covered algae in contrast continued to grow luxuriantly for 2 weeks, when the experiment was ended.

These observations support the conclusion that the unvegetated sand strip is produced by grazing of fish that live on the reef. Interestingly, the sharpness of the seaward border of the strip depends more on the vegetation present than on reef characteristics. Where turtle or eel grass borders the reef the outer edge is far more sharply drawn than where *Udotea* or other algae is the dominant vegetation. This situation is probably due to the denser growth of the grass compared to the algae.

The sand tilefish is an interesting geological agent in the distribution of coarse shell and coral fragments on the flats adjacent to the reef. The fish builds nests by depositing shells and coral around large dead coral heads exposed on the sand flat. Geologically it is important to know if the fish concentrates the shells from the substrate where the nest is built (a sorting process) or by carrying them in from the flats adjacent to the nest (transport and deposition). Observation of one fish via an underwater TV camera for several days indicated that most of the material is transported to the nest. This conclusion was supported by incorporation into the nests of fresh *Acropora cervicoinis* fragments that were placed on the sand near the nests. The fish seems to construct his nest by sweeping the sand clear with his belly and tail and building a roof by dropping shells and coral over the top. The shells in a sand tilefish nest nearby all lie concave-up. A single fish seems to continuously build and abandon a nest within a matter of days. Over a period of time these fish obviously can greatly modify the distribution of coarse fragments on the flats near the reefs.

Other geologic studies pertained to the history of sea-level changes in the Virgin Islands. Standby aquanaut R. L. Phillips of the Geological Survey identified and mapped an extensive beachrock submerged about 20 feet below the present sea level. Rounded pebbles of the volcanic bedrock, generally restricted to the beach, were abundant in about 400 feet of water around 400 feet north of the habitat. This observation not only indicates a previous stand of the sea some 40 feet below the present surface but also suggests that limited subsequent deposition in Lameshur Bay, a conclusion supported by the presence of coral pebbles and cobbles 60 to 65 feet beneath the surface about 1000 feet south of the habitat in an area where present-day sediment should be much finer. Acoustical subbottom profiles taken across Lameshur Bay under the direction of L. E. Garrison of the U.S. Geological Survey prior to the dive show a flat bedrock platform, probably an ancient wave-cut platform underlying greater Lameshur Bay. Recent marine fossils were found and collected from about 65 feet above sea level at White Point, attesting also to higher stands than at present.

A complex recent history of Lameshur Bay is indicated by the three-dimensional relationship between coral reef and carbonate sand. Near the habitat the living coral of the reef is growing laterally over the sand floor, suggesting that reef growth presently exceeds reef destruction. Similarly, in the patch reef area northeast of the habitat, isolated living coral heads are expanding laterally over the sand substrate. The sand, however, forms but a veneer over a solid mass of buried dead reef. These observations suggest a complex history of reef growth and destruction. The reef on the southeastern side of Lameshur Bay originally extended much farther than at present. North of the habitat the original reef was largely killed and covered with a veneer of sand. Renewed present coral growth is indicated by the lateral growth of living coral heads over the sand and by the coalescing of the larger heads in the eastern part of the patch reef into crude spurs parallel to the present direction of wave approach.

Of very recent origin are blocks of volcanic bedrock that lie scattered atop the coral reef proper. The blocks are of similar size, roughly 10 to 20 inches long, 6 to 12 inches wide and 2 to 6 inches thick. Most are crudely rectangular and have unrounded edges and corners. Each is cemented into place and is 10 to 50 percent covered by coraline growth. The blocks show no obvious variation in size with distance from the nearest outcropping bedrock, and grooves or topographic lows lie between the blocks and the outcrops. Rubble obviously derived from the outcrops, in contrast, grades into subrounded pebbles a short distance from the source and show no evidence of upslope transport. These data suggest the blocks were artificially emplaced; perhaps they are ballast stones dropped separately from vessels in the days when Lameshur was an active plantation, or possibly they were weights for native fish traps.

Tektite I demonstrated that underwater habitation offers great advantages to investigations of marine geology. Perhaps the most impressive feature was the wide range of geological studies that could be made during the project. Only a small number of these could be attempted, and fewer still could be completed within the time of the underwater habitation. The possibility of nearly continuous observation offers tremendous advantage to the marine geologist. The application to studies of marine geological processes, to underwater exploration of mineral resources, and to geologic studies of the relationship of the *underwater* sea floor to man's environment (such as earthquake hazards) are manifold.

Several persons contributed to the geological program. The role of R. L. Phillips deserves particular mention. In addition to discovering the submerged beachrock, he mapped the bottom types over a wide portion of the southeast coast of St. John. He also supported the habitat-based program by conducting necessary analytical and preparatory work. Two other geologists from the Geological Survey visited the project site. Joshua I. Tracey helped greatly in the establishment of an offshore 1000-foot grid system used for navigation and location and in preparation of a bathymetric chart of the area, and Gil Corwin examined the bedrock in the area of the experiment and contributed to the bathymetric chart by photogrammetric techniques.

A2 PSYCHOLOGICAL SCIENCES

A2.1 Overview of the Program

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A2.1.1 Introduction

Historically, Project Tektite I was conceived because of speculation concerning the behavior of small groups of highly motivated, scientifically oriented individuals who must live and work together over a prolonged time (60 days) in a real, "hostile" environment from which they cannot be extricated easily. The crew would be occupied with real tasks which would be almost entirely self-generated and with minimal external direction (interference) except for safety considerations.

Data relating to the total psychological sciences program were collected in three phases: predive, during the 60-day saturation dive, and postdive. The types of data can be categorized broadly into four general subprograms (to be discussed in sections A2.2, A2.3, A2.4, and A2.5 respectively): behavioral program, sleep electroencephalographic (EEG) records on two of the crew on magnetic tape and on paper (ink-writeout), sleep EEG records on a third crew member using an electrode cap and an automatic sleep-stage analyzer, and psychomotor testing using a device that presented complex visual-motor-cognitive tasks.

A2.1.2 Predive Tests

A2.1.2.1 Behavioral Program

The major portion of the predive testing consisted of a detailed and in-depth interview to obtain demographic information to serve as a base for all subsequent observations.

The predive testing was done during the base-line biomedical data collection period at the University of Pennsylvania hospital. Also, this period was used for indoctrination of the divers concerning what measures would be taken, the noninterfering anonymity, and the reasons for each and all observations.

Base-line mood scales were obtained each day during this 10-day period. The rationale for these pencil and paper tests were given and their importance to the program stressed in order that each diver would complete one each day of the dive.

Additionally, a Rorschach protocol was administered to each diver and backup diver in the same way as given in the space program to each astronaut. The results showed no indications which would compromise the 60-day mission. Incidentally, no further discussion will be made of these data.

A2.1.2.2 Sleep EEG (Navy)

One set of EEG data were obtained from two of the divers (designated divers 1 and 3). Base-line recordings were made at the U.S. Navy Neuropsychiatric Research Unit in San Diego. Personnel from this laboratory designed and assembled the instrumentation, collected the data, and made the analysis. Six channels of data include two of EEG data, two of EOG data, one of EKG data and one of muscle potential. During the acquisition of the base-line data both divers obtained instruction on electrode positioning and emplacement. The adequacy of the instruction and the learning was demonstrated in the quality and high consistency of the recordings.

A2.1.2.3 Sleep EEG (NASA)

The second set of sleep EEG data was obtained by a system designed for space application. Base-line recordings on diver 2 were made in Houston at the Baylor University hospital using an electrode cap developed for NASA and feeding recording devices and an automatic sleep-stage analyzer which Baylor scientists had designed and assembled for NASA. The analyzer provides a direct readout of the sleep stage an individual is in during any period of his total sleep cycle. The stages are labeled 1 through 4.

A2.1.2.4 Psychomotor Test

The divers were indoctrinated on a psychomotor device during the biomedical base-line testing at the University of Pennsylvania hospital. The device, designed and built by NASA Langley scientists and called the complex coordinator, presents complex psychomotor tasks involving the matching of a sequence of lights by the manipulation of four controls (one for each extremity). The display of lights is programmed to be adaptive; i.e., when the patterns are rapidly matched by the individual, the sequences become more difficult, and if the tasks become too difficult, the patterns become easier. The device is portable and self-contained. Initial measures were obtained during this period, and a suggested, but not rigid, schedule was agreed on.

A2.1.3 Testing During Operations

A2.1.3.1 Behavioral Program

The data collection system was designed to obtain objective behavioral observations (records) capable of sufficient detail that analyses could reveal consistencies and variations of the life and work of the four crew members, over time, across men, subgroups, and the total group during the 60-day mission. Highly detailed, noninterfering observations were made each 15 minutes during the total mission on general activity, task performance, social relations, communications, personal habits, and emotional adjustments.

Section A2.2 will give the preliminary findings and projections for the complete analysis of the 500,000 individual data points.

A2.1.3.2 Sleep EEG (Navy)

The sleep EEG data obtained by the Navy system on two of the divers yielded 52 man-nights of sleep records. Recordings were made on each man each night during the first 10 days, then were made every third night during the midperiod of the mission and each night during the last 10 days. The records, with the exception of a single channel (out of six channels) which became noisy for a couple of nights, were of exceptional clarity and quality. This was in spite of self-applied electrodes, 1000 feet of cable underwater from the habitat to the recording site in the control van, and the frequency and duration of the recordings. Exhaustive analyses will not be accomplished, even using computer reduction, for some time.

A2.1.3.3 Sleep EEG (NASA)

The NASA sleep EEG system obtained data on diver 2 on the same schedule of nights of recording as outlined above for divers 1 and 3. Data accumulating to 24 man-nights of sleep were collected from diver 2. As with the Navy system the NASA system yielded records of exceptional quality. One minor difficulty was that the cap containing the electrodes was not as comfortable at the normal gravity state of the habitat as it would be in a zero-gravity state. However, in spite of the comfort factor, the quality of the recordings remained excellent.

A2.1.3.4 Psychomotor Test

The psychomotor test series can partly be considered nonscheduled in that there was no set time for each aquanaut to test himself on the device but partly considered scheduled in that each was recommended to devote some time per day to match his skill with the instrument.

A2.1.4 General Comments

Each of the major sections of the behavioral program were designed to be able, upon analysis, to interrelate with each other. Because of the computer-oriented data-handling capabilities provided to the project, intercorrelations of almost infinite permutations are possible. Many will be made in subsequent publications planned by each major investigator. It will also be possible to relate behavioral data to biomedical data and each, or both, to the various aspects of operational data. The results given in this overall Tektite I report are general and broad in scope. They will serve to identify areas of interest and the scientists who will ultimately provide the complete analyses.

A2.2 Behavioral Program

Roland Radloff and LT. Richard Mach, Behavioral Sciences Department, Naval Medical Research Institute, Bethesda, Maryland and Nicholas Zill, Bellcomm, Inc., Washington, D.C.

A2.2.1 Purpose of the Behavioral Program

The purpose of the behavioral program must be understood in the context of the purposes of other programs on Project Tektite I, whose goals are outlined briefly as follows:

- Collection of marine scientific data from an ocean floor habitat employing saturation divers.

- Demonstration of the capabilities of saturation diving techniques.

- Study of the physiological reactions of man to long-term exposure to a shallow-depth nitrogen-enriched atmosphere.

- Testing of an underwater habitat and support facilities.

- Demonstration and test of the capabilities of Navy personnel in a diving operation at a remote site.

- Collection of electroencephalographic data on sleep during long periods of isolation and confinement in an unusual environment.

- Collection of microbiological data on a closed environment over a relatively long period of time.

- Study of the behavioral reactions of individuals and a group to long-term isolation and confinement in a real setting. In addition the results of the behavioral program were intended to provide an understanding of the reactions of men to undersea and space environments.

Because of the multiple purposes of Tektite I, the behavioral program was potentially subject to interferences from and compromises with other goals and requirements. Recognition of and accommodation to other requirements of the program was an essential part of planning data collection for the behavioral program.

Ironically, however, the greatest difficulties grew out of misconceptions of the psychological concepts of isolation and confinement and of the ways in which Tektite I data were applicable to space flight and other extreme environments. The problems stemming from inadequate understanding or misinterpretation of the purposes of the behavioral program are simple and yet profound. These problems were pervasive in the extreme, affecting almost every other aspect of the program.

What is meant by saying that the purposes of the behavioral program themselves had the greatest potential for interfering with the success of that program? This question has many facets, and complete and detailed consideration of it is not appropriate to this report. However, it is necessary in understanding the execution of the behavioral program to discuss some illustrative aspects of the question.

Let us consider what is meant by isolation. To someone not interested in studying the effects of isolation, this may seem to be a simple question. A brief analysis will demonstrate that it is highly complex. The phrase "the lonely crowd" implies that persons may be isolated even though they are physically close to large numbers of their fellow human beings. Psychological isolation is difficult if not impossible to define as a concept, since it is subject to individual and experiential definition. Physical isolation, on the other hand, is quite easy to define; and it is relatively easy to design a situation which will produce physical isolation. However, physical isolation cannot define, even though it will affect significantly, the individual definitions of psychological isolation. Furthermore, there is potentially a vast difference in psychological reaction to physical isolation produced artificially as compared to naturally occurring physical isolation. Lack of understanding of this and a number of other factors by various persons in Project Tektite I were potentially very disrupting to the behavioral data collection program.

When studying isolation as a variable in a real setting, the only way of cutting through the confusing dilemmas posed by attempting to define isolation in the abstract is to accept the natural influences on the phenomenon produced by considerations other than those of a behavioral science program. The principle here is a variation of the Heisenberg principle, that the act of measurement interferes with the phenomenon being measured. With psychological variables, Heisenberglike effects are more pervasive than they are with physical variables. In many instances, artificial attempts to produce a variety of phenomena in real life settings for the purpose of studying them will have self-defeating effects on the phenomena under study.

The camel has been described as a horse designed by a committee. In some respects Project Tektite I was such a creature. The multiple purposes of the project produced minor anomalies in all phases of the program. Since we are interested here in the behavioral program, let us consider an example which will illustrate how the major purpose of the behavioral program was in danger of subversion by the multiple purposes of Project Tektite I. The illustrative example is crew composition.

At one point in the proposal for Project Tektite I, the following crew composition was entertained: one marine scientist, one scientist assistant who was also an astronaut trainee and a diver, a habitat engineer-diver, and a physician-diver. This crew composition was proposed in an attempt to simulate the composition of a space flight crew. The consideration of such a crew illustrates a basic misunderstanding of the purposes of the behavioral program. Since one of the purposes of the behavioral program was to generalize conclusions regarding crew productivity, interaction, and adjustment to outer space crews, it might seem reasonable that the best way to do this would be to simulate a space crew in composition, and so it did seem to many persons.

However, the simulation of a space crew by artificial composition overlooks one fundamental class of variables, intrinsic attractions to the environment. It seems relatively easy for most persons to understand that simulations lack the realistic stresses of natural environments. However, the fact that simulations also lack the realistic attractions of natural environments is quite frequently overlooked. It is a mistake to suppose that overall realism can be achieved if only the stresses or the attractions are permitted to vary naturally. If either factor (stresses or attractions) is artificially manipulated, a simulation rather than a natural environment is the result. It is clear that a saturation diving environment contains some real stresses which are of interest to persons wishing to make a generalization to outer space environments. Furthermore these real stresses are very difficult if not impossible to produce in a simulation both because of ethical and practical considerations. By the same logic the intrinsic attractions of a saturation diving environment are difficult if not impossible to simulate. Hence intrinsic attractions as well as intrinsic stresses both must be permitted natural variation, since the validity of reactions to a natural situation depends upon the presence of both.

The basic position here is that the undersea environment is *analogous* to outer space but cannot be a *simulation* of a space environment. Understanding the behavior of men and crews in exotic environments will be severely degraded if an attempt is made to create a simulation of an outer-space environment under the sea. This has proved to be a very difficult concept to grasp; however, its appreciation is important, not only in understanding the present study but in planning future programs. Therefore let us examine it a bit further by use of an analogy.

Suppose that a researcher was interested in investigating success or failure of basketball teams. Suppose further that for some reason, it was impossible to study basketball teams directly to develop predictive information on effectiveness but that it was possible to study hockey teams. Hockey teams might appear to be a reasonably analogous group to study in order to better understand the general variables influencing the success of basketball teams. Both games are played indoors, basketball teams have five players and hockey teams have six, offensive and defensive strategies are roughly similar, both sports are fast paced and have time-limited periods, and so on. Further examinations of alternative approaches might indicate that hockey teams are more similar on relevant variables to basketball teams than are either football or baseball teams.

By studying hockey teams as hockey teams, we could investigate influences on success in areas such as team cohesiveness, coaching, morale, group interaction outside of the game, rate and kinds of substitutions during the game (bench strength), ability of players, variability in ability, and a variety of variables conceptually similar to those influencing the success of basketball teams. If hockey teams were to be studied to develop information predictive of the success of basketball teams, it is unlikely that anyone would propose that basketball players be inserted into the hockey teams under study. It should be clear that such a move would undermine the purpose of developing information on influences predictive of the success of hockey teams specifically and of athletic teams in general. The situation would be degraded even further if, in the interests of studying extreme variations in team composition, football and baseball as well as basketball players were added to a hockey team.

The foregoing analogy is incomplete and may be inaccurate in some respects, as all analogies are. However, it may serve to illustrate the point that the value of Project Tektite I for generalization to outer space is its similarity in conceptual rather than in purely physical dimensions. Variations in crew composition or any other variables of operational significance in natural settings must be dictated by and consistent with the operational requirements of the situation. Crews should be composed of persons whose background, interest, and training are appropriate for the environment in which they work. Furthermore, in natural environments, crew members must have roles which are essential to their participation in the program. Fortunately, such was the case in Project Tektite I. There was natural rather than artificial crew composition.

Considerable time has been spent in discussing a point which may appear to many to be quite esoteric and beside the central purpose of the behavioral program. It is important to an understanding the behavioral program that there is a full appreciation of the centrality of this point. Behavioral scientists felt that throughout the program there was an inadequate understanding, or in some cases a complete misunderstanding, of the purpose of the behavioral program on Project Tektite I. These misunderstandings resulted in inevitable compromises for the behavioral program. The points at issue are so central and pervasive and at the same time so subtle and seemingly contradictory that a full appreciation of them is unlikely. Their understanding is especially crucial to follow-on programs. There is a distinct danger that follow-on programs will err in the direction of greater simulation of physically real but psychologically unreal approximations of outer space environments. The result would be not only inefficient and inadequate marine science but also invalid or meaningless results for generalization to the space program.

Crew composition was only one of the many areas in which misunderstanding of the behavioral program produced pseudo-problems and compromises in the conduct of Project Tektite I. In numerous other areas the behavioral program was inappropriately asked to carry the burden of a decision either in whole or in part. In some instances decisions were made, and in others decisions remained in limbo; and there was no clear-cut policy.

For example, regarding food, questions were raised as to the type of meals and frequency of resupply. These questions should have been decided on the basis of convenience to the crew, cost, storage facilities, crew preferences, time required of support personnel, the overall impact on the marine science program, or similar considerations. If nutritionists or physiologists wished to learn of the adequacy of various diets from the standpoint of supplying energy or of palatability or similar interests, the studies could have been designed with those purposes in mind, and they would have had a minimal impact on the behavioral program. Such studies should be designed by specialists in the areas of nutrition or physiology. As in the case of crew composition, however, food should *not* be viewed as something on which global behavioral reactions can be studied by manipulating various diets or methods of preparation for the purpose of studying *psychological* reactions to such variations.

Similar questions arose concerning communications, how much to permit and what restrictions to impose. Communications should not be viewed as an aspect of the behavioral program. Whatever communications were economically feasible and necessary for the marine science program, for health and safety monitoring, and for like interests, should have been included with no question of restriction to produce feelings of isolation. Resupply of the capsule also raised inappropriate questions in the behavioral area. Some initial suggestions were made that the habitat have no resupply from the surface to increase the feeling of isolation. When it was noted that such a restriction would necessitate stocking the capsule with supplies of dry towels and baralyme to the extent that the structure would be bursting at the seams, the proposal was dropped. Once again, however, it is instructive to note that such a restriction was proposed on the basis of false assumptions about the behavioral program. Questions of entertainment facilities and equipment, which could and should have been answered on the basis of space and reasonable needs of the occupants also became confused by misunderstanding of the concept of isolation. Issues such as whether the aquanauts should communicate with family, have visitors to the habitat, and have discussions with scientific colleagues, some issues being trivial but some important and some ludicrous but some serious, were needlessly considered and discussed as to their impact on the behavioral program.

Not all artificial manipulative interventions in the name of producing this or that psychological state are equally disturbing; and there appear to have been no serious interventions in Project Tektite I. However, the sheer number of questions raised in considering the study of reactions to long-term isolation and confinement meant that crew members reacted unnaturally to perceived or actual attempts to produce certain psychological variables. Fortunately it seems that naturally existing influences inherent in Project Tektite I were of sufficient strength to minimize the participants' reactions to extraneous pseudo-psychological variables.

In summary, in studying psychological reactions to phenomena in real settings, it is imperative that the manipulation of variables not be instituted for the sole or even the primary purpose of producing an intended psychological effect. This is so because the artificial manipulation of psychomimetic variables in natural environments creates the danger that reactions will be influenced less by the variable which has been manipulated than by the fact of the manipulation of the variable itself — a Heisenberg effect in spades! This position does not mean that variables cannot be manipulated. It means simply that such interventions must be effected for other than academic psychological interest. Planned interventions will be most successful when they are demonstrably consistent with the primary goals of the person whose behavior is being studied. The proper posture for a behavioral program in a natural environment is piggyback not monkey-on-the-back.

The preceding orientation guiding the conduct of the behavioral program can be correctly perceived as radical and uncompromising. It is probably also relevant and correct to note that this orientation is a minority position within the field of psychology. Most research psychologists are trained and practice in the laboratory. The orientation of laboratory training and practice is toward manipulation and control of variables. There is no conflict between the manipulation and control orientation, which is appropriate for laboratory studies, and a hands-off naturalistic observational approach, which is appropriate for most field settings. (There are studies which are true field experiments, but they are so rare and the conditions of their execution are so involved that it would only confuse the present discussion to consider such studies in detail here. We do recognize the existence of field experiments but maintain that the orientation guiding such studies is inappropriate to the studies of saturation diving.) The approach guiding the behavioral program of Project Tektite I maintains only that radically different methods are necessitated by the different environments of the laboratory and the field. Maintaining the need for different approaches in the laboratory and the field does not imply that one approach is better than the other. The use of either approach will depend upon the goals of the research project. Since in Project Tektite I the objective was to observe the behavior of a natural group in a real setting, the approach employed followed naturally from that objective. Many of the specific decisions and actions taken by persons connected with the behavioral program may have seemed to others to be illogical and arbitrary. The above discussion is intended to explain the way in which they followed naturally from the basic guiding orientation of the program.

This detailed discussion of potential pitfalls should not obscure the fact that the basic goals of the behavioral program were fully realized. Although the orientation expounded here may not have been fully understood, it was sufficiently appreciated and practiced that the basic purpose of the behavioral program was realized beyond the most optimistic expectations of the investigators. A major contribution to the success of the behavioral program was the understanding by the four crew members themselves of the purposes of the program. In the final analysis we were able to study the behavioral reactions of individuals and a group to long-term isolation and confinement in a real setting.

A2.2.2 Conceptual Orientation of the Behavioral Program

Considerable attention has been devoted to explaining the "why" of the behavioral program. "What" was done was rather simple and straightforward. Just as the design phase of a field study requires natural rather than artificial production of the effects under study, so also does measurement of the variables require a reliance on unobtrusive or nonreactive measures of real events. Operations of the data collection phase of the program involved the collection of simple, objective records of ongoing behavior in a regular systematic fashion. The conceptual orientation guiding data collection was initially developed on Antarctic wintering-over parties studied by Gunderson and Nelson;* it was applied to the study of Project Sealab II;† and its use in Project Tektite I represents a refinement of concepts and methods used in the Sealab II research, taking into consideration the similarities and differences in the Sealab and Tektite I environments and the data collection facilities available. Maximum reliance was placed on observations of ongoing behavior, with minimum reliance on measures involving subjective self-report such as responses to checklists, diaries, and the like. When behavior can be observed, there is no need to ask the participants to record and interpret their own actions. Similarly, responses were measured on real rather than artificial tasks. If participants have meaningful work to perform of intrinsic interest to themselves, there is no need to insert artificial tasks to obtain measures of performance. The key concept behind the behavioral observation was nonintervention or unobtrusive measurement. This approach can perhaps be best appreciated by conceiving of the behavioral data collection on Project Tektite I as similar to keeping a score card on a team in an athletic contest.

Tektite I provided unexcelled opportunities for collection of on-line data from an operational group in the real world. The data collection program was designed to take maximum advantage of these opportunities. Continuous TV and audio access to all

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*E. K. E. Gunderson and P. D. Nelson, "Criterion Measures for Extremely Isolated Groups," Personnel Psychology 19, 67-80 (1966).

†R. Radloff and R. L. Helmreich, "Groups Under Stress: Psychological Research in Sealab II," New York, Appleton-Century-Crofts, 1968, chapter 5.

sections of the capsule were available. Tektite I provided an opportunity to collect data of laboratory quality in a field setting. Another way of stating the goal of data collection was that it was designed to observe and record data in sufficient detail so that analysis could reveal consistencies and variations over time and across men, subgroups, and the total group and reveal responses to significant environmental events. In brief the system was designed to obtain objective behavioral records capable of describing and explaining the life and work of the four-man crew of Project Tektite I over the 60 days of their mission.

A2.2.3 Psychologically Distinctive Features of Project Tektite I

Psychologists were interested in studying Project Tektite I because the opportunity to study any group is of interest to psychologists. However, Project Tektite I had some distinctive features of especial interest to psychologists.

Of primary interest was that Project Tektite I was a saturation diving project. This meant that the men were subject to naturally existing conditions of interest to psychologists desiring to study humans under stress. There is no question that the saturation divers were under stress; furthermore those stresses were not imposed or contrived by psychologists. Since they were saturation divers, the Tektite I aquanauts lived in an exotic environment. They were separated by 19 hours from a return to the normal world. Their extended temporal separation was, of course, due to the long and careful decompression required after their body tissues became saturated with gas under pressure. They were subject to danger from equipment failure or human error which could have resulted in fatal or disabling accidents. They breathed an exotic gas mixture under pressure. Although the divers in Project Tektite I were not subject to the severe thermal stresses characteristic of many diving ventures, passage through the benthic barrier into the world of water occurred daily for them. Tektite I divers, as all saturation divers, depended highly on each other and on surface support personnel. Although the stresses in Project Tektite I were not as severe as they have been in other saturation diving groups, the novelty of the situation, the isolation from family and normal society, the dangers involved in saturation diving, and the temporal separation of 19 hours from normal society required by decompression were interesting naturally existing variables in their environment.

On the other side of the coin were the attractions of Project Tektite I for the aquanauts. Marine scientists are interested in using saturation diving techniques primarily for their own purposes. While previous saturation diving programs had included projects designed to collect some marine science data, this was the first project specifically designed to collect marine science data as the major purpose of the project. This meant that the divers in Project Tektite I were eager volunteers whose motivation was high, and there was assurance that their motivation would be sustained by tasks of intrinsic interest to them. Such motivation may be contrasted for example with the reluctant participation of volunteers in laboratory and simulation studies of isolation and confinement. Such men perform, for the most part, tasks of little interest or meaning to them personally. Project Tektite I represented the fulfillment of long-standing ambitions of the participants.

The opportunity to collect real data by unobtrusive means was another attractive feature of Project Tektite I. Since safety and medical monitoring necessitated TV and audio coverage of the habitat, psychologists could observe the behavior with a minimum likelihood of reactions to their observations. The divers realized that the watchful eye of big brother was there for their safety. It is true the Tektite I aquanauts knew that they were being observed by psychologists and that records of their reactions were being made, but it is also true that they would have been observed had psychologists not been there and that their reactions would have been noted, although not on a systematic basis.

Thus observations are, in a sense, normal features of saturation diving environments, and the presence of psychologists can be expected to affect the reactions minimally.

A2.2.4 Data Collection System

A2.2.4.1 On-Site Punching of Direct Observations on Data Cards

The system of collecting behavioral observation data was designed to demonstrate that simple, objective observational measures can produce a rich, meaningful picture of human behavior in a field setting, provided that the number and frequency of these measures is large enough to do justice to the complexity of the situation. This prototype system was an engineered gamble for expanded capability over more conventional collection procedures. A direct observational approach was employed, an extension of the method used by ethologists and anthropologists. The guilding philosophy is: given a field, naturalistic setting wherein exercising of controls is difficult if not impossible, the researcher builds his study not around controlled experimentation but around measures which make sense in describing the natural, on-going behavior *within* the constraints of the particular territory, area, or situation being investigated. The hope is that reduced reliability due to lack of experimental control is more than compensated for by the robustness or validity of the observed behavior. Methodological difficulties appear not in designing the conditions of the research but in developing and implementing measures which preserve the naturalness of behavior by not intruding or manipulating in any way the object of observation in his domain yet get inside what is going on through a deceptively simple, descriptive procedure.

Within the Tektite I project were a number of built-in elements challenging the observation program in general and the data collection program in particular. Some strictly operational aspects were very early defined, and others arose from the investigators' particular orientation tempered by the context of those operations. This array of factors served to shape the boundaries within which the collection system had to evolve and operate. Briefly they were as follows:

- The entire undersea mission would actually take place just off an island remote from any civilization center. This assured a relatively pure, stable, marine ecology for scientific inquiry but also insured a plethora of logistical difficulties inherent to such a removed site.

- The aquanauts would live exclusively under the sea for a considerable duration, be generally isolated from the topside world, and be physically separated from the behavioral investigators.

- A large pool of attractive, descriptive behavioral measures unusual and often unique to conventional psychological assessment was available, as a result of prior research and continued development, for further validation as well as initial testing.

- The measures would be collected through systematic direct observation and, for certain indicators, with high frequency so as to emphasize a comprehensive view of behavior.

- The behavioral program policy was to employ an unobtrusive, noninterference collection methodology such that the natural, on-going activity of the aquanauts in the habitat would not be disturbed. Signals from the closed-circuit TV cameras and open microphones in the habitat would furnish the majority of the observational data.

- An experimental instrumentation package designed to electronically monitor and automatically record certain activities in the habitat would be implemented.

- Slated for concentrated training in a highly synchronized, involved data collection procedure as behavioral observers were enlisted seamen of predominantly untested and thus unknown quality.

- Program policy dictated that almost all behavioral data leaving the site would be on punched computer cards to eliminate time-consuming off-line reduction, speed information feedback from the computer to the site, and maximize use of observer time.

- Sizable time and cost constraints would prevent implementing elaborate instrumentation and procedures for data collection but instead would foster an elegantly simple, inexpensive, easily imitated system.

Within the context of these major considerations then the collection system was designed, developed, and finally implemented. The following description of the system will become more meaningful when integrated with the description of the data management program in section A4. Data flow from the project reached Washington once a week to be sorted and analyzed by already existent computer programs and promptly returned to the site. Access to analytic and storage computer facilities played an integral part in the construction of the collection system.

The heart of the data acquisition system was the recording of directly observed events by a trained observer using an IBM information recorder. Although described in detail in section A4, the information recorder can briefly be characterized here as a small, portable, plastic unit which allowed different information-filled templates to be superimposed over partially preperforated data cards. These cards could be punched on-line, with the resultant record being fully compatible with the specially composed read programs of the Washington computer. The device was untried, but its potential advantages over the gathering of the more conventional paper and pencil records were convincing. Dealing with the quantity of behavioral information under active consideration during the planning phase made handling of the projected mountains of paper undesirable. Location of the one appropriate checklist in 25 during a frantic recording session is time consuming. Trying to maintain a reasonable ordering of checklists during recording sessions and a cataloging procedure which allows relocating any specific piece of information would have been virtually impossible. Finally the reduction of huge amounts of paper and pencil data to a format compatible with computer devices is such a formidable task as to have surely been delayed until after the active collection phase, preventing any comprehensive feedback of analyzed data during the mission.

The information recorder solved most of these problems. As will be detailed in section A4 the different templates required design and setting-up procedures far more detailed than a paper and pencil checklist, because of the necessity to optimize the use of available space on the compact template field. Beyond this was a complicated, time-consuming procedure in the manufacture of each separate template. These two factors in turn operated on two aspects in the conceptual stages of behavior measure development. First, the rationale concerning which measures would finally be used and how elaborate each would be demanded continued scrutiny throughout their development to prevent wasting valuable time on measures that would never be used. In short, the investigators were forced into rigorous, well-reviewed decisions about measures. Second, checklists would have allowed flexibility for change right at the site, in the midst of the collection phase if need be. The prepared template did not. Flexibility is usually desirable, but not at the expense of putting off decisions which should be made prior to the data collection phase. The researcher, with the promise of easy modifiability, often excuses himself from the difficult task involved in making a commitment to his final family of measures.

The standardized format across templates cut down on search time for the observer recording any particular event and permitted a data acquisition rate (recording speed) commensurate with the more familiar medium of paper and pencil. Error rate proved to be low. Recorders were always reloaded with blank cards after use, and templates that were frequently used remained in their respective recorders, saving the time otherwise spent changing templates. Storage of the punched cards was simple. Data punched on site were partially reduced, eliminating the usual reductive steps of reordering and key punching the data before analysis. Deciding on the content of the measures and design of the templates well in advance of the mission's commencement allowed for an early start to the writing and debugging of computer programs for data sorting and analysis. As a result analyzed data could be returned to the site during the mission. These data provided insight into on-going individual and group processes and permitted evaluation of, and corrective feedback to, observer personnel through a variety of checks built into the measures.

A2.2.4.2 Choice of the Objective Measures

The majority of measures finally settled on for Tektite I were extensions of those used in research on Sealab II and were based on directly observable, objective events. The major focus of the measures was directed at assessing task performance, social interaction, and emotional adjustment. In fact, six general categories of information were collected: time coding of a variety of events either in terms of time of occurrence or time to accomplish; performance evaluation using both quantitative and more subjective, qualitative measures; description of aquanaut disposal in terms of habitat location, general activity, and communication status; aquanauts' conversations within the habitat and with topside; a simple frequency count of certain prespecified events; and aquanaut mood. These measures were carefully developed to insure redundancy on some crucial indicators by partially overlapping certain of them. During development, stress was placed on simplicity and directness of meaning for the eventual observer. This face validity made intuitive sense to our observers and their work all the more meaningful to them.

A2.2.4.3 The Observers and their Training

The behavioral program had six observers available at all times to support the collection phase and from one to three supervisors on-site maintaining the program. Six Navy seamen apprentices just out of a training command in Orlando, Florida, had been selected through regular channels on the basis of a minimum General Classification Test score of 60 (placing them intellectually in the top 10 to 15 percent of the general population), a clerical interest, and strong motivation toward and interest in the project.*

The observers arrived at the base camp 2-1/2 days before the mission's start. Their training began immediately, with reading of a detailed 44-page manual which defined every behavioral indicator, described use of the equipment, and contained a glossary of terms and an overview of the project. During the first full day at the base camp, except for a short trip to view the behavioral station, the men concentrated on the manual. On the second day, as fragments of understanding fell into place, possible collection situations were simulated in a base camp classroom, since the behavioral station was much too small for simultaneous use by the six observers. The manual was in frequent use during the first few days of the mission, then, as the observers' understanding matured, served as a handy clarifier of the finer points of collection.

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*Because of their excellent contributions as observers as well as their valuable and ingenious suggestions which furthered the technical efficiency of the overall collection program we take pleasure in citing the names of the six observers: Thomas Boyd, Robert Holston, William Quintard, Joseph Mayberry, Dan Friar, and Robert Littlewood.

Since the quality of the men could hardly be known 4 to 6 months in advance, a concerted effort had been made to create collection procedures as simple as was reasonable without jeopardizing the main thrust of the program. Such emphasis proved to be fortunate in that the complete procedure proved somewhat difficult to learn within the short time allotted. The observer was asked to consider himself the scorer of a ball game, being sensitive to recording certain important events while disregarding others. He was to serve as a chronicler of on-going activities, answering who, what, when, and where kinds of questions.

As the mission started with but 2 days of instruction and simulation behind them, further team training was accomplished on-line with each pair of observers, particularly during the first 2 days of the mission. With the supervisors providing extensive support the quality of the data was not seriously affected during that time, although frenzy abounded within the behavioral station those first few days.

In retrospect the actual training phase went very quickly. After the first few days of the mission the observers were thoroughly competent to deal with every operational aspect and general maintenance of the topside instrumentation complex. In general they were highly motivated, had excellent esprit de corps, and attacked the challenge with relish. This competence was such that later in the mission the major supervisory problem was dealing with the boredom of the observers and its ramifications for degradations in vigilance and ensuing reduction in data quality.

A2.2.4.4 Active Phase

Although both the behavioral station and its monitoring and recording equipment will be described in detail in Appendix B (section B5.2), brief coverage is warranted here. The behavioral station was one of two sections of a van mounted on a barge winched above the surface of Lameshur Bay on pilings (Figs. 29 and 30, page 41). The watch director's section provided safety personnel with instrumented monitoring of the atmosphere and visual monitoring of the aquanauts in the habitat plus a centralized communication system with the habitat, crane barge, safety boats, and base camp. Aquanaut behavior within the habitat was monitored and recorded in the behavioral station.

General Electric personnel responsible for equipping the support van received substantial inputs concerning overall design and equipment placement within the station from the Naval Medical Research Institute. Such personalized decisions about floor plan layouts and design of the central equipment control consoles and switches in the habitat allowed a configuration of the station best suiting the peculiar demands of the collection program. The Naval Medical Research Institute's Behavioral Sciences Department instrumentation laboratory meanwhile was developing the fundamental equipment package for the van. Installation took place in General Electric's Valley Forge facility, in the Philadelphia Navy Yard, and on site in Lameshur Bay. Premission hookup and comprehensive checkout were accomplished on site. Detailed maintenance instructions and critical spare parts were available as precautionary measures.

Once the station was fully operational, it was literally packed with equipment and support instrumentation. Behavioral observers manned six closed-circuit TV monitoring screens and audio inputs from habitat compartment cameras and open microphones as well as audio tape recorders for recording conversation and a video tape recorder for visual records. They operated this array of equipment from centralized control consoles, employing the information recorders and checklists in their collection.

Meanwhile an equipment package automating the monitoring and recording of the use of certain habitat facilities unobtrusively collected its information at the rear of the station. This electronic monitoring was certainly the exemplar of the behavior program's unobtrusive guidelines garnering performance indicators, use of time, and use of entertainment facilities. It provided a backup account of diving time *when* aquanauts punched "in" and "out" buttons on a dive panel near the rim of the ingress—egress hatchway. On–off piggyback switches on the habitat's entertainment TV, AM-FM radio, and stove switches supplied information illustrating the patterns of use of facilities and gave possible indication of the well-being of the crew and its individual members. Finally, microswitches on each aquanaut's bunk headphone signaled disclosures of the private use of entertainment facilities. In short the system allowed thorough monitoring of highly specified units of behavior, some of which occurred almost instantaneously and others of which were screened from observer view by the location of the operator aquanaut between the particular facility and the TV camera.

A2.2.4.5 Collection

On occasion the aquanauts were continuously monitored around the clock, but over the greater part of the mission data were collected continuously from 6:15 a.m. until 11:45 p.m., 17-1/2 hours per day. This period was found to cover about 97% of the aquanaut's waking hours. The observer work shifts, between 2 and 6 hours long, depended on the evolving boat transportation and chow schedules. Observer performance depended not only on personal motivation and competence but on the capacity to maintain considerable vigilance over prolonged periods of time. Early in the mission it was obvious that watch periods 2-1/2 to 3-1/2 hours long appeared to optimize the tradeoff between constantly shifting the observers, causing a loss in continuity of recording, and the overly long periods where the likelihood of poor-quality data is increased because of a reduction in observer vigilance.

Watch schedules and thus boat transportation to and from the support barge were designed by the command for the convenience of the watch-director contingent. This schedule, because of an acute boat shortage, was changed repeatedly over the first few weeks of the mission along with accommodating changes in chow schedules. The behavioral watch schedule had to be adjusted continually to fit these permutations. As a result protracted observer watches had to be maintained. Later in the mission a special early morning shuttle was instituted for the observers to accommodate the needs of the behavioral program. It was pointed out that a late night shuttle would prevent the loss of valuable data being generated by the aquanauts, who were staying up beyond the midnight change of the topside watch, the point at which the observers had to return to the base camp or be left on the support barge overnight. For the ubiquitous and convenient reason of "safety" this request was unacceptable to the command. Such a lack of appreciation for what doing science involves interfered with the on-going scientific endeavor.

The information recorder, a small number of backup checklists, the audio recorders, and the electronic monitoring system were employed as primary devices for gathering information either as it materialized (on line) or sometime after its occurrence (off line). Checklist data were punched off-line onto cards as were the paper-tape records generated by the digital printer of the automated monitoring system and the crew responses on the mood adjective checklists. Two primary behavior sampling procedures were employed during the collection. Event sampling required the recording of prespecified activities as they occurred in the context of on-going behavior and time sampling noted certain standard components of aquanaut behavior at prespecified intervals. These intervals, generated on a random basis to prevent introduction of a sampling bias, were short enough to insure that the data collected were representative of the continuity of the on-going behavior within those intervals.

The flavor of the actual collection situation can best be conveyed by describing a few moments of activity within the behavior station. Both observers are seated at the working table monitoring the TV screens. It appears the four aquanauts are just finishing their lunch in the crew quarters. One of the observers is busy punching information describing various aspects of the meal. He is also punching intermittently a "communication with topside" record, since an aquanaut is talking with topside personnel through the intercom. The second observer has just finished a time-locked sampling of the location, activity, and communicative status of all the aquanauts and is preparing to obtain a conversation record, since the three men left at the lunch table are talking. A crew member has just climbed the ladder into the bridge, so our second observer punches this as a transit for that man on the transit record. Operating the remoted switching of his control console, the first monitor starts the audio tape recorder, records his identifying comments, and begins taping the conversation. At the same time, he operates a multiple-tone-generating device which codes the duration and sequences of the conversational inputs of each aquanaut on a parallel track of the tape. The habitat conversation suddenly breaks up, with two of the men transiting around to the wet lab (more transit records are punched) to retrieve a large pressure pot from the surface. The first observer notes the use of the winch, size of the pot, and its contents on a checklist. The only man left in the crew quarters brings to a close the meal recording as he begins picking up the dishes and tidying the cooking area. He turns off both the stove and the radio, triggering separate pulses topside which are translated and then printed out by the electronic monitoring and recording system onto paper tape. This information will later be punched onto computer cards.

A new template is brought into play as the wet lab pair, now finished with the pressure pot, don their scuba equipment for an excursion around the reef. The second observer has assisted the first during the recent flurry of activity but must now return to the location record according to his list of sampling times. Next he moves to the rear of the station, changing the spent audio tape reel, then identifying, boxing, and storing it for shipment. In checking the various cue lights indicating the on-off status of different habitat facilities, he notes two just blinking on, indicating divers 2 and 3 punching "out" on the dive panel as they enter the diving trunk. He also finds the paper-tape record of facilities usage in good order.

It should be fairly evident from the preceding description that the realm of duties of each man of the monitoring team was well structured. One was locked into a time sampling procedure but would assist his fellow with event and frequency sampling during periods of heavy activity in the habitat. Teamwork within each observer pair was encouraged, since a smooth back-and-forth flow of responsibility proved to be a necessity. The veracity of the data collected was evaluated by the supervisor, checking the observer periodically for accuracy in the recording of objective data, whereas for more subjective data continued agreement between monitor and supervisor was the desired criterion. Although close supervision was demanded as a prerequisite to good data early in the mission, the observers were gradually allotted differing levels of responsibility and assumed comparable degrees of autonomy.

The promise held within the system was realized. Over the 60 days of the mission nearly half a million digits of behavioral data emanated from the support barge. The observers, and the system they operated, interfaced smoothly with the data management program. Major goals set were accomplished. The first postmission task now lay in reviewing the robustness, accuracy, and power of the data — performing the necessary error checking and editing before launching into comprehensive analysis.

A2.2.5 Background Information on the Aquanauts

A2.2.5.1 Sources of the Information

Background information was collected on each of the aquanauts at the University of Pennsylvania in January 1969. Two standard psychological inventories, the Allport

Vernon Lindzey Scale of Values and the Edwards Personal Preference Inventory were administered. Team members completed two other questionnaires, a biographical inventory, derived from research on Antarctic groups, and a swimming questionnaire, recently developed for divers. The information from these questionnaires is intended for use in a data bank for comparison with other groups of men in similar environments, including other diving groups. The information is largely technical and will not be reported here. Descriptive information obtained from a structured biographical interview which was administered at the same time, will be reported. Brief, preliminary, and tentative interpretations of the biographical information will be made to indicate its possible use in predicting behavior.

The structured biographical interview was a 1-1/2-hour interview with broad questions followed by specific probes depending upon the answers given. It investigated such areas as education, employment (including work as a child), family, finances, hobbies, and sports. The information will be reported for the group as a whole with indications of similarities and differences given for specific responses.

A2.2.5.2 Age

The Tektite aquanauts were all in their middle and early thirties. The senior man of the group was 35 and the others were 34, 32, and 31. Thus, the group was quite homogeneous in age. Furthermore their ages are similar to those of other groups of men entering unusual environments for first-of-type ventures, such as Project Mercury astronauts, the American Mount Everest climbing team, and the aquanauts of Sealabs I and II. It is quite likely that in all the instances cited the age of the men was a highly influential factor in their selection. That is, in selecting men for unusual environments, it is necessary to have men who have sufficient experience such that their potential is known, yet who are young enough that they have sufficient stamina and resilience to withstand the rigors of unusual environments. It can therefore be expected that most of men entering such environments will be in the age range of the Tektite I aquanauts.

A2.2.5.3 Education

One of the men held a Ph.D. degree, two others held Master's degrees, and the fourth held a Bachelor's degree. Their education from their earliest years through college was comparatively smooth and regular. As can be expected of college graduates, they all did quite well in their early years of schooling, with the exception of one of the men, who was a high school dropout. However, his intellectual ability enabled him to qualify for his high school degree in the Navy through general education courses. Upon leaving the Navy he entered college and continued in a smooth course toward his degree. None of the other men had had any difficulties while in school, and the man who had earned a Ph.D. had been an outstanding student throughout his educational career. The others were in the top 1/4 to 1/3 of their classes as a general rule from high school years on. Thus in the area of education we have a group with a history of comparatively regular and even progress toward degrees.

While the attainment of advanced education was desired by their parents, the men were required for the most part to finance their education by themselves. Only one of the men did not work during the school years while in college, and he earned a portion of his college expenses through summer employment. The rest of the men financed their education through a variety of part-time jobs, scholarships, and assistantships. Thus they are a comparatively highly educated group, who worked for what they attained. Only two of the men had their education interrupted by military service, and in both cases the military service was not exactly an interruption. One of the men learned diving while he was a Navy enlisted man, and this skill proved to be highly consistent with and helpful in his later education as a marine biologist. The other man served as an officer in the chemical corps of the army. Hence there was some professional involvement in his military service. All the men attended large public coeducational colleges as undergraduates. The entire educational experience of all these men was in public schools, with the exception of one of the men who attended a private school for his graduate degree.

A2.2.5.4 Employment

All four of the men have worked for the Department of the Interior since completing their education. One is a staff oceanographer, another is a marine geologist, and the other two are marine biologists. It is interesting to note that even though the four men as a group had a wide variety of part-time jobs during their college years, including summer work, and several of them during their high school years, that their only employment since completing their education has been with the Department of the Interior.

A2.2.5.5 Present Family

All four of the aquanauts are married. Two of them have three children, one has two children, and the fourth has no children. Two of the men were married at a fairly young age, one at age 20 and the other at age 21. The other two men were married at ages 24 and 26. The men who are fathers were ages 23, 25, and 27 at the birth of their first child. In all cases their first child was born after they had finished their Bachelor's degree. This situation may indicate the ability to plan rationally and to delay gratification, since these men found it necessary to finance most of their undergraduate education, which would have been much more difficult had they been family men at the time. The marital and family status of these men is quite similar to the status of other men entering unusual environments such as the Mercury astronauts, the Mount Everest climbing team, and the Sealab II divers.

A2.2.5.6 Childhood Experience and Adult Interests

All four of the men were born during the middle or late depression. Although they were raised in different areas of the nation, many of their childhood experiences were quite similar. They were raised in Florida, Ohio, the state of Washington, and Colorado. Each of the four men spent his entire childhood and youth in a relatively small geographic area, with one minor exception of a long-distance move in infancy for one of the men. Even though two of the men were raised in or near medium-sized cities, the childhood experiences had an outdoors, semirural quality for three of the men. Three of the men were earning regular incomes by the age of 11, two of them by paper routes and one by working in a store. After that age they held a wide variety of part-time jobs during the school years and during the summers. They were all given some regular household chores at the age of 6 or 7, including chores such as taking care of the family garden, mowing the lawn, and feeding chickens. Hence learning the responsibilities and discipline of work began at a comparatively early age for all four of the men, especially for the three who began earning regular incomes at a young age. All four of the men attended church regularly in childhood and through adolescence, and all four were quite active in the Boy Scouts.

Interest in outdoor activities has carried over into adulthood. They also have in common an interest in working with their hands. All four of the men share wood working as a hobby in one form or another, ranging from constructing buildings as a hobby to refinishing antique furniture. Two of the men were avid collectors as children; one of them specialized in rock and leaf collections, and the other maintained as many as 35 aquaria. One of the men was a gourmet cook, a fact that was greatly appreciated by his team mates. All of the men were quite healthy during childhood with the exception of one relatively long term respiratory illness for one man. All four were quite active in sports in their youth, participating in athletic activities much more for the personal enjoyment or satisfaction and camaraderie involved than for status enhancement or recognition of outstanding performance.

A2.2.5.7 Parents

The parents of all four of the men are living and living together. This objective indication of stable family background is supported by many of the comments of the men. For all four men the father appeared to be the strong figure in the family. The ages of their fathers at the birth of each man were 26, 29, 34, and 36. All four of the men are the first-born males in their families; one man has an older sister. Each of the men has exceeded his father in education, income, and job status. However, since this upward mobility was achieved with the support and encouragement of their parents, each man spoke of his father with respect and warm affection. They all recognized that economic conditions in the depression set limits on their fathers' achievements. Thus the fact that they have been able to achieve a higher status than their fathers has made them grateful for and respectful of their parents' efforts and encouragement.

A2.2.5.8 Summary

This brief global description of these four men presents far from a complete picture of the path which ended in their participation in Project Tektite I. Nevertheless some indications of the major influences in their lives emerge from this description. Each of the men came from a relatively stable, secure family background. They all had records of quite steady and smooth achievement, educationally and vocationally, not exceptionally brilliant or outstanding in any case but in all cases successful and leading them to higher stages of development and accomplishment. Their fathers especially seemed to have been strong and positive models — companions but yet distant enough to provide authority and guidance during their formative years. Stability, solid accomplishment, and an even development are the major themes in all cases, beginning with early childhood and continuing from adolescence. Experiences in their families of origin are seen again in their present families and in their stable work situations. While it may be a slight deviation from scientific objectivity, it is relevant to observe that these men are easy to know, to like, and to respect.

A2.2.6 Results

A2.2.6.1 Location of the Total Crew

Where did the men spend their time? The data presented in this section are taken from the location record. This was a record of the location of each man taken on a random basis once within every 15-minute period throughout the course of the mission, 17-1/2 hours per day. The data in Fig. A2 give the percentage of time spent in each of the major compartments, or in the water, each day. Superimposed on these percents is 7-day moving average to smooth out variations in proportions in time spent in various areas. It excludes a small proportion of time spent in the tunnel and in the cupola.

There are several interesting trends in these several graphs. Note first of all the decrease in the amount of time spent in the bridge area, which is compensated for by an increase in the amount of time in the wet laboratory and in the water over the course of the mission. The men became increasingly efficient in their biomedical measurement tasks, which were conducted in the bridge, as the mission progressed, and less time was spent for habitat maintenance and repair, allowing them more time for diving and related activities in the wet laboratory. Note that the two curves representing time in the wet laboratory and in the water are almost identical. This is not surprising, since the more time the men spent diving, the more time they spent preparing for and securing from dives and processing specimens brought in from dives.

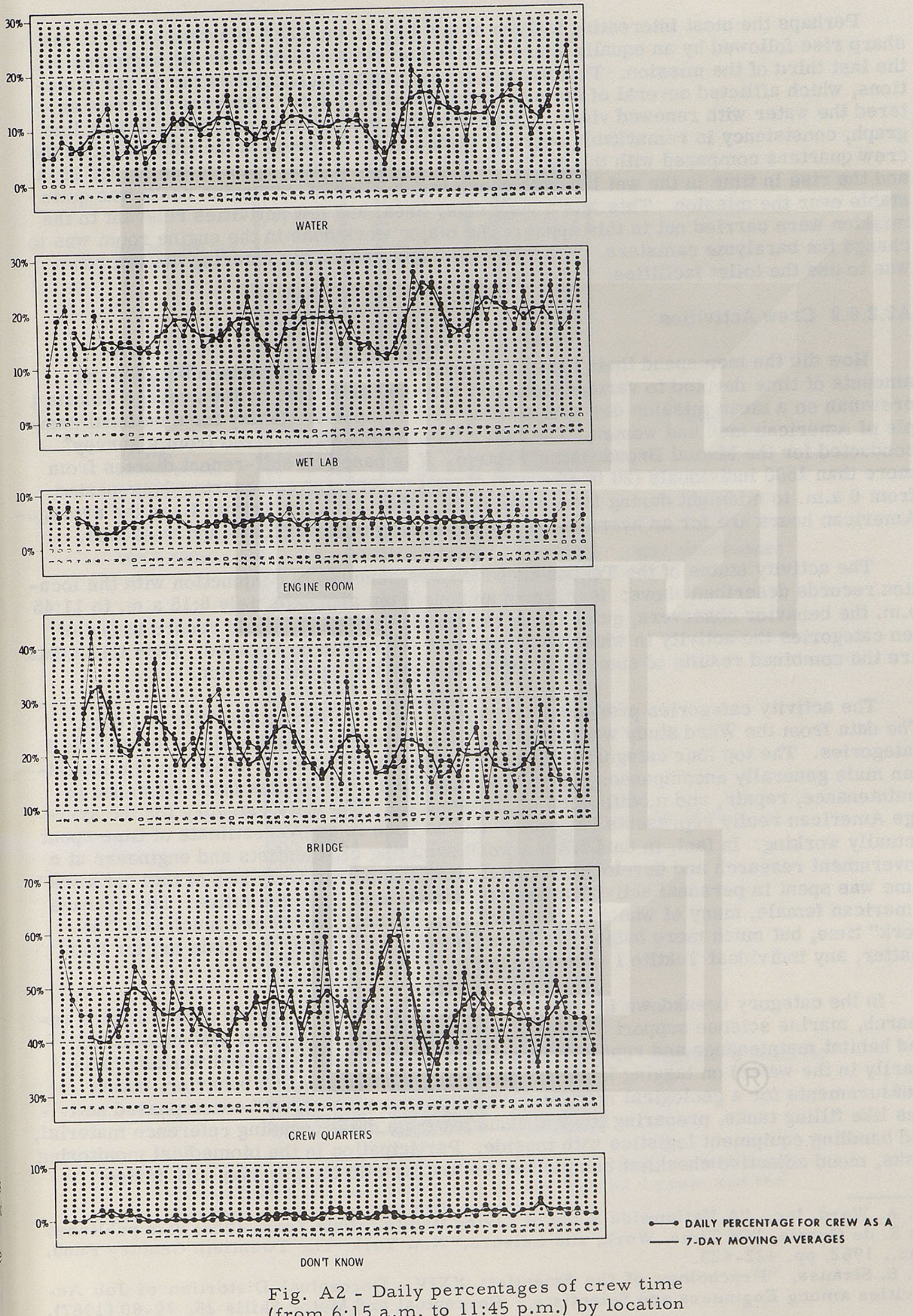

Fig. A2 - Daily percentages of crew time
(from 6:15 a.m. to 11:45 p.m.) by location

Perhaps the most interesting feature of the data on the crew quarters graph is the sharp rise followed by an equally sharp decline just prior to and after the beginning of the last third of the mission. This feature of the graph was accounted for by ear infections, which afflicted several of the men simultaneously. After recovery the crew entered the water with renewed vigor. Other than this one striking excursion in this line graph, consistency is remarkable over the period of the mission in the time spent in the crew quarters compared with the decline in the amount of time spent in the bridge area and the rise in time in the wet laboratory and water. Use of the engine room was quite stable over the mission. This was a very noisy area, and few activities relevant to the mission were carried out in this space. The major work done in the engine room was to change the baralyme canisters. The other principal reason for entering the wet room was to use the toilet facilities.

A2.2.6.2 Crew Activities

How did the men spend their time? Figure A3 shows a comparison between the amounts of time devoted to various work and personal activities by the average Tektite I crewman on a mean mission day with similar data on an average day for a national sample of American men and women. The latter information was derived from a survey* conducted for the Mutual Broadcasting System. It is based on self-report diaries from more than 1500 individuals (20 to 59 years of age) covering every quarter-hour period from 6 a.m. to midnight during March and April 1954. Both the Tektite I and the average American hours are for an average day, incorporating both weekdays and weekends.

The activity status of the Tektite crewmen was sampled in conjunction with the location records described above: four times an hour from approximately 6:15 a.m. to 11:45 p.m. the behavior observers, guided by a randomized schedule, would record in one of ten categories the activity in which each aquanaut seemed to be engaged. Thus these data are the combined results of some 4300 records taken during the mission.

The activity categories presented are those used in collecting the Tektite I data. The data from the Ward study were regrouped to be roughly comparable to the Tektite I categories. The top four categories represent time spent working, which for the American male generally encompasses his work at the office or shop plus labor expended in maintenance, repair, and modification of his domicile. The work category for the average American really represents "at work," and as such is an overestimate of time spent actually working. In fact, in data from a work sampling of scientists and engineers at a government research and development installation,† approximately 25% of this "at work" time was spent in personal activity at the office or absent from the office. The average American female, many of whom do not work outside the home, shows much less "at work" time, but much more habitat/house maintenance time than the male or, for that matter, any individual Tektite I crew member.

In the category breakdown for the aquanauts, included as work are direct marine research, marine science support activities, biomedical and behavioral self-monitoring, and habitat maintenance and repair. "direct marine research" involved working (primarily in the water) on tagging lobsters, observing lobster and fish behavior, taking measurements for a geological map, etc. "Marine science support" encompassed activities like filling tanks, preparing for and securing from dives, reading reference material, and handling equipment logistics with topside. Participation in the biomedical monitoring tasks, mood adjective checklist completion, or testing with the psychomotor device

*J. A. Ward, Inc., "A Nationwide Study of Living Habits," New York, 1954; data published in S. de Grazia, "Of Time, Work, and Leisure," New York, The Twentieth Century Fund, Inc., 1962, pp. 422-423.

†P. S. Strauss, "Psychology of the Scientist: XXIV - Perceptual Distortion of Job Activities among Engineers and Scientists," Perceptual and Motor Skills 25, 79-80 (1967).

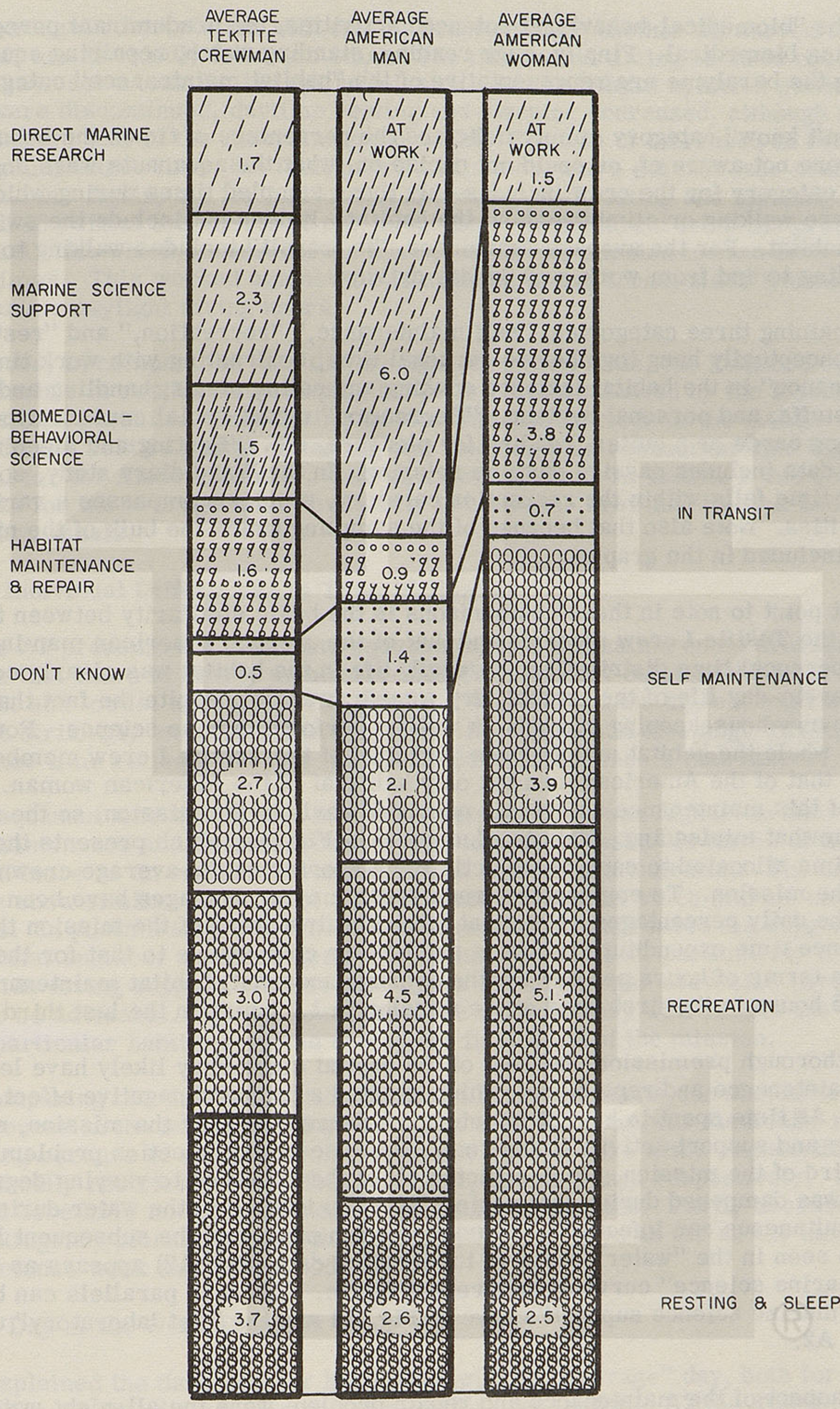

Fig. A3 - Comparison of the average day's time use in hours (from 6:15 a.m. to 11:45 p.m.) by the Tektite I crew and the average American man and woman comprised the "biomedical-behavioral science" activities, the predominant percentage of this time being biomedical. Finally, gage reading, standing watch, repairing equipment, and changing the baralyme are representative of the "habitat maintenance" category.

The "don't know" category simply indicates the percentage of times the behavioral observers were not aware of, or could not decide on, what the aquanauts were doing. The "in-transit" category for the crew includes only those sampled times during which the aquanauts were walking or climbing about the habitat. It does not include the swimming outside the habitat. For the average Americans, "in transit" includes walking to the store, traveling to and from work, and Sunday driving.

The remaining three categories, "self maintenance," "recreation," and "resting and sleeping," conceptually hang together as personal time, contrasting with work time. "Self maintenance" in the habitat included cooking and eating meals, handling and transporting foodstuffs, and personal hygiene. "Recreation" meant social conversation after dinner, playing cards or a guitar, reading for pleasure, etc. "Resting and sleeping" in the Tektite I data includes passive daytime relaxing. In the Ward diary study, some of this relaxing time falls within the recreation category, which encompasses a variety of leisure activities. Note also that because of the sampling times the bulk of the night's sleep is not included in the graphs.

The first point to note in these comparisons is the basic similarity between the average day of the Tektite I crew member and that of the average American man in terms of work and personal time distribution. Overall, life in the habitat was clearly comparable to the day-to-day life of the normal, dry American male, despite the fact that the crew had to carry housekeeping burdens as well as perform marine science. For the mission as a whole the habitat maintenance workload of the Tektite I crew members averaged twice that of the American man but only half that of the American woman. However, much of this maintenance and repair occurred early in the mission, so the mean figure is somewhat misleading. This is illustrated in Fig. A4, which presents the percentages of time allocated to each of the activity categories by the average crewman on each day of the mission. To emphasize trends 7-day moving averages have been superimposed on the daily percentages. Note that after the first third of the mission the repair and maintenance time expenditure becomes much more comparable to that for the American male. In terms of hours per day for the average aquanaut, habitat maintenance time went from 2.5 hours in the first third of the mission to 1.1 hours in the last third.

A more thorough premission checkout of the habitat could very likely have lessened this initial maintenance and repair load, which exerted a profound negative effect on crew productivity. As time spent in habitat maintenance decreased over the mission, marine science diving and support activity times rose. Because of ear infection problems during the second third of the mission, which afflicted all of the crewmen to varying degrees, the increase was dampened during that period. The dip in time in the water during the period of simultaneous ear infections, the postinfection peak, and the subsequent leveling-off which was seen in the "water" curve of the location data (Fig. A2) appears as well in the "direct marine science" curve of the present figure. Likewise parallels can be seen between the "marine science support" curve of Fig. A4 and the "wet laboratory" usage curve of Fig. A2.

Another aspect of the maintenance and repair problem were the all-night watches which the crew stood on a 3-hour rotating schedule during the first third of the mission, until confidence in the reliability of habitat systems could be established. (Watch-standing time is shown separately in Fig. A4. In the other figures it has been incorporated into the habitat maintenance category.) This watch standing reflects itself in the large fraction of the day spent in resting and sleeping during the first third of the mission. This disruption of circadian rhythms, the hectic pace of premission preparations, and the continual confrontation with one malfunction after another all served to get the mission off to a decidedly lethargic start. The nature and timing of these occurrences may well have set a tone for the entire mission. As the habitat systems settled down and watches were discontinued, daytime resting and sleeping decreased, although remaining at a level above that of the American male norm. Because of increases in recreation and self-maintenance time, the total personal time showed a net increase over the course of the mission. Again, the fluctuations in recreation and resting and sleeping over days 35 through 45 reflect the effects of ear infections. Not apparent from the present graphs is a gradual shift which occurred over the course of the mission toward later arising and retiring times. This worked against the increasing diving trend, since it meant the loss of some prime daylight diving hours.

However, in comparison with the average American male, the Tektite I crew's greater number of resting and sleeping hours is counterbalanced by the lesser time spent in recreational pursuits. Only during the ear infection periods of the middle third of the mission did the Tektite I total of resting and sleeping plus recreation time exceed the same total for the American male. Self-maintenance time in Tektite I was consistently higher than for the average male, primarily because the crew had to cook and clean up after its own meals.

A2.2.6.3 Individual Differences in Time Utilization

Table A1 presents the individual aquanaut's time utilization on an average mission day. Note that there is nearly an hour's difference per day between the total work time of the highest and lowest aquanaut. The aquanaut who showed the highest total work time also spent strikingly less time than the others in resting and sleeping. His higher self-maintenance time reflects the fact that he prepared more meals than others.

The aquanaut who was lowest in marine science time was highest in time devoted to habitat maintenance and to the conduct of the biomedical tests. In terms of time spent he functioned more as an engineer-technician than as a marine scientist. The other three aquanauts show similar patterns of worktime allocations, in which marine science predominates. In postmission debriefings the aquanauts all expressed the suggestion that an actual habitat engineer would be desirable on future missions, particularly if he could also provide diving support. In line with this a slightly larger crew size (five or six) was thought to be advisable. Again, however, these opinions may well reflect the unreliability of these particular habitat systems during the first third of the mission.

In comparing the time utilization of the different aquanauts one should bear in mind the differences in the number of days on which each aquanaut was medically restricted from diving because of ear infections or, in one case, a sore arm. Aquanauts 1 through 4 were medically restricted from diving on 12, 1, 3, and 7 days respectively. The data presented here have not been corrected for these differences. Partly because of inadequate contingency planning, these were essentially lost days as far as the individual's marine science work was concerned.

A2.2.6.4 Day of the Week Patterns

As explained the data thus far have dealt with an "average" day, both for the Tektite I crew and for the Ward study comparisons. As shown in Table A2 the Tektite I crew did not follow the American pattern of taking the weekends off from work. There was less total worktime on Sundays, but not strikingly so. During the concentrated diving activity in the last third of the mission, *more* diving was actually done on Sundays than on the surrounding days.

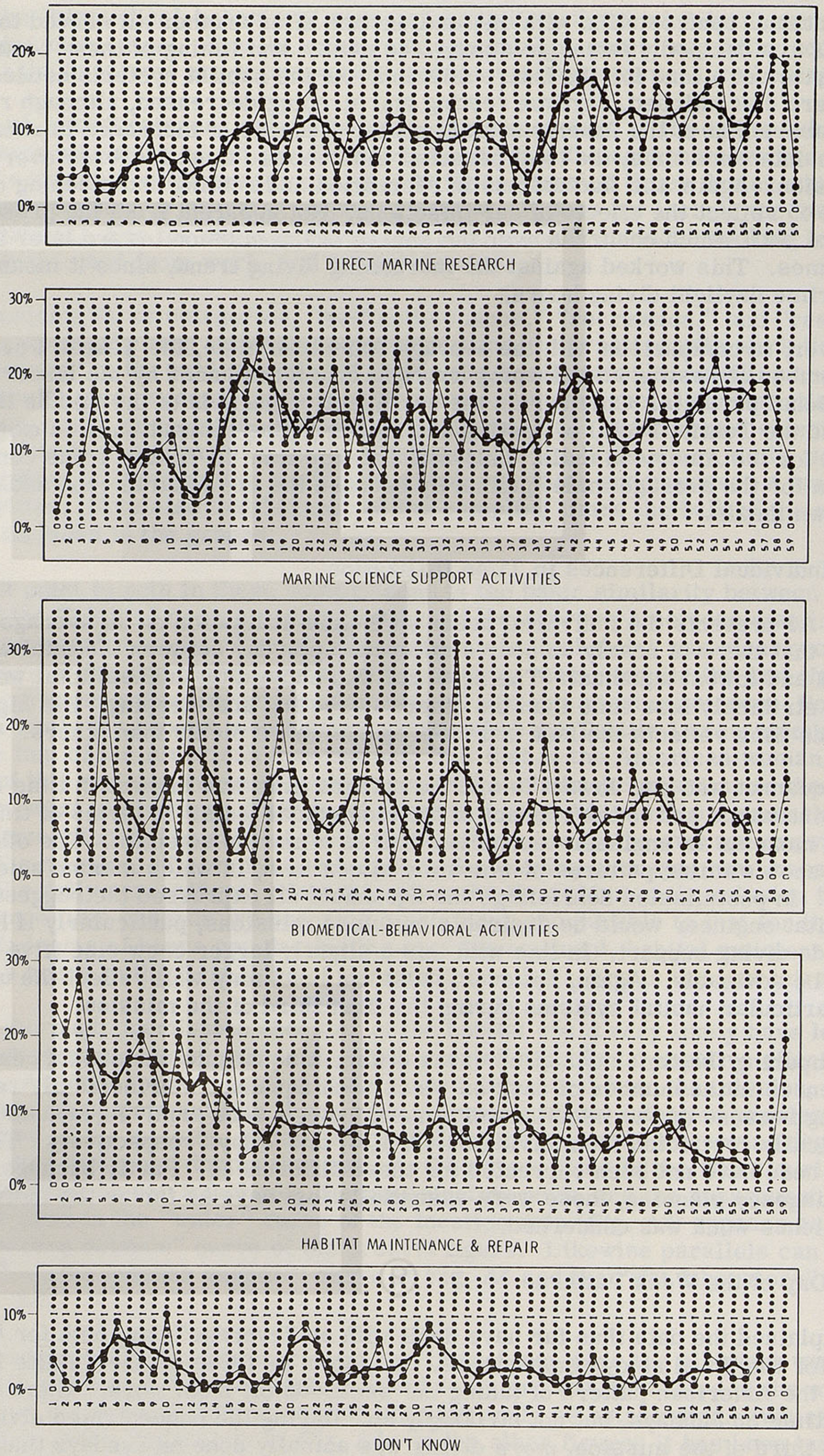

Fig. A4 - Daily percentages of the time from 6:15 a.m. to 11:45 p.m. that the Tektite I crew spent in activities. The curves show daily averages and 7-day moving averages. This figure continues on the next page.

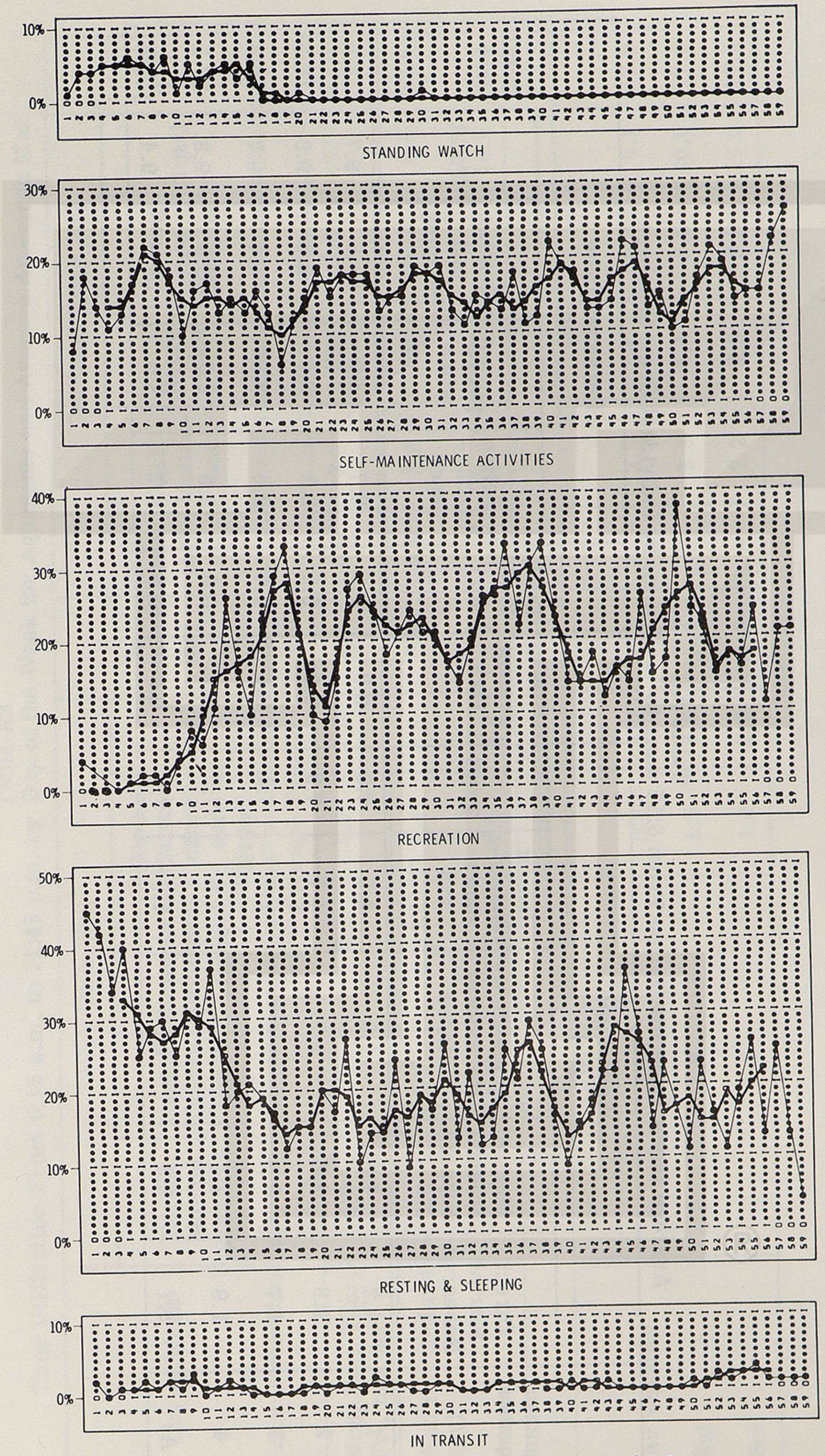

Fig. A4 - Daily percentages of the time from 6:15 a.m. to 11:45 p.m. that the Tektite I crew spent in activities. The curves show daily averages and 7-day moving averages.

Table A1
Average Day's Time Utilization From 6:15 a.m. to 11:45 p.m. by Individual Crew Members

Aquanaut Number	Work Time (hr)					In Transit (hr)	Don't Know (hr)	Personal Time (hr)				Total (hr)
	Direct Marine Research	Marine Science Support	Biomedical-Behavioral Science	Habitat Maintenance and Repair	Total			Self Maintenance	Recreation	Resting and Sleeping	Total	
1	1.2	1.8	1.8	2.2	7.0	0.2	0.6	2.7	3.2	3.8	9.7	17.5
2	1.9	2.6	1.7	1.7	7.9	0.1	0.5	3.1	3.1	2.8	9.0	17.5
3	1.7	2.5	1.4	1.7	7.3	0.1	0.4	2.5	2.8	4.4	9.7	17.5
4	1.9	2.4	1.3	1.9	7.5	0.1	0.6	2.6	2.9	3.8	9.3	17.5
Av	1.7	2.3	1.5	1.9	7.4	0.2	0.5	2.7	3.0	3.8	9.4	17.5

Table A2
Time Utilization From 6:15 a.m. to 11:45 p.m. by Day of the Week for Aquanauts and Average American Man

Day of Week	Work Time (hr)					In Transit (hr)	Don't Know (hr)	Personal Time (hr)				Total (hr)
	Direct Marine Research	Marine Science Support	Biomedical Behavioral Science	Habitat Maintenance and Repair	Total			Self Maintenance	Recreation	Resting and Sleeping	Total	
Average Tektite I Crewman												
Mon, Tue, Thur, Fri, and Sat	1.9	2.5	1.2	1.9	7.5	0.2	0.5	2.7	3.0	3.6	9.3	17.5
Wed (biomedical day)	1.0	1.7	3.8	1.6	8.1	0.2	0.4	2.8	3.0	3.0	8.8	17.5
Sunday	1.6	2.2	1.0	2.0	6.8	0.2	0.5	2.9	3.0	4.1	10.0	17.5
Average American Man												
	At Work (hr)											
Av weekday	7.2			0.8	8.0	1.4	–	2.2	3.6	2.3	8.1	17.5
Sat	4.3			1.2	5.5	1.4	–	2.5	5.5	2.6	10.6	17.5
Sun	1.2			1.0	2.2	1.3	–	2.2	7.9	3.9	14.0	17.5

A much more distinct difference from the daily pattern occurred on Wednesdays; on these biomedical monitoring days the structure of the monitoring schedule was imposed on the crew's activities. Note that although these medical procedures did cut into marine research and marine support time, the overall work time was higher on Wednesday, than on the other days of the week. Resting and sleeping was less on Wednesdays, again reflecting the scheduled arising time enforced by topside on these biomedical days.

A2.2.6.5 Activity and Location

The preceding two sections discussed the location of the men and some of their activities. This section will examine the influence of activities on the location of the men and the crew. The capsule was divided into four compartments. The compartments were further subdivided for purposes of data collection such that 30 total sections, most with functionally distinct characteristics, were identified on the location record. Since the men were in the capsule approximately 90% of their waking hours, each compartment would have been used 22.5% had they been occupied equally. Further, if each of the 30 areas for which data were collected had been occupied an equal proportion of the time, each area would have been occupied 3% of the time. There are obvious reasons to expect some compartments and some areas within those compartments to have been used more than others.

This was the case. We have seen in the location data for the total crew that the crew quarters and the bridge were occupied more than other areas. The men were in the crew quarters almost 45% of their waking hours and 51% of the time they were in the capsule. The bridge was occupied 21% of the total waking hours during the mission and approximately 23% of the time the men were in the capsule. Thus the men were in either the crew quarters or the bridge 66% of their waking hours and 74% of the time they were in the capsule. Since most of the time was spent in the crew quarters and in the bridge, we will examine representative data from these two compartments to illustrate the manner in which the functional configuration of the space and the use of that space by individuals and the group determined its occupancy.

Tables A3 and A4 present data on the average time spent in the crew quarters and the bridge as well as occupation of the most heavily used space in each. The man spending the greatest amount of time in each compartment and its most heavily used section is compared with average occupancy of that compartment and that particular section by the other crew members. That is, this detailed analysis will focus on the compartment and the space within the compartment most utilized.

Table A3 gives the average amount of time spent in the bridge and the mission experiment area (section 4) of the bridge for diver 2 and the other crew members. The following interpretation of these data demonstrates a situation approaching the establishment of territorial dominance, over the course of the mission, of the most desirable space by the man appearing to have had most need of that space.

For the total mission diver 2 was in the bridge 1 hour more per day on the average than were the other three men, who were fairly equal in their occupancy. This additional hour per day was spent by diver 2 in the mission experiment area of the bridge (Fig. A5). This area was by far, the most preferred sitdown area in which to work within the capsule. Its average usage by the crew was 9% of the total time in the habitat, three times that of the use of that space expected from a random distribution of usage. Diver 2 had a particular task which required his frequent use of this area. Week 1 data in Table A3 show that during the first week diver 2 was not in the bridge or in section 4 of the bridge more than were the other men. However, in the second week he had begun to use both the bridge and mission experiment area more than the other men. By the third week of the mission his additional occupancy of the bridge and experiment area had reached its

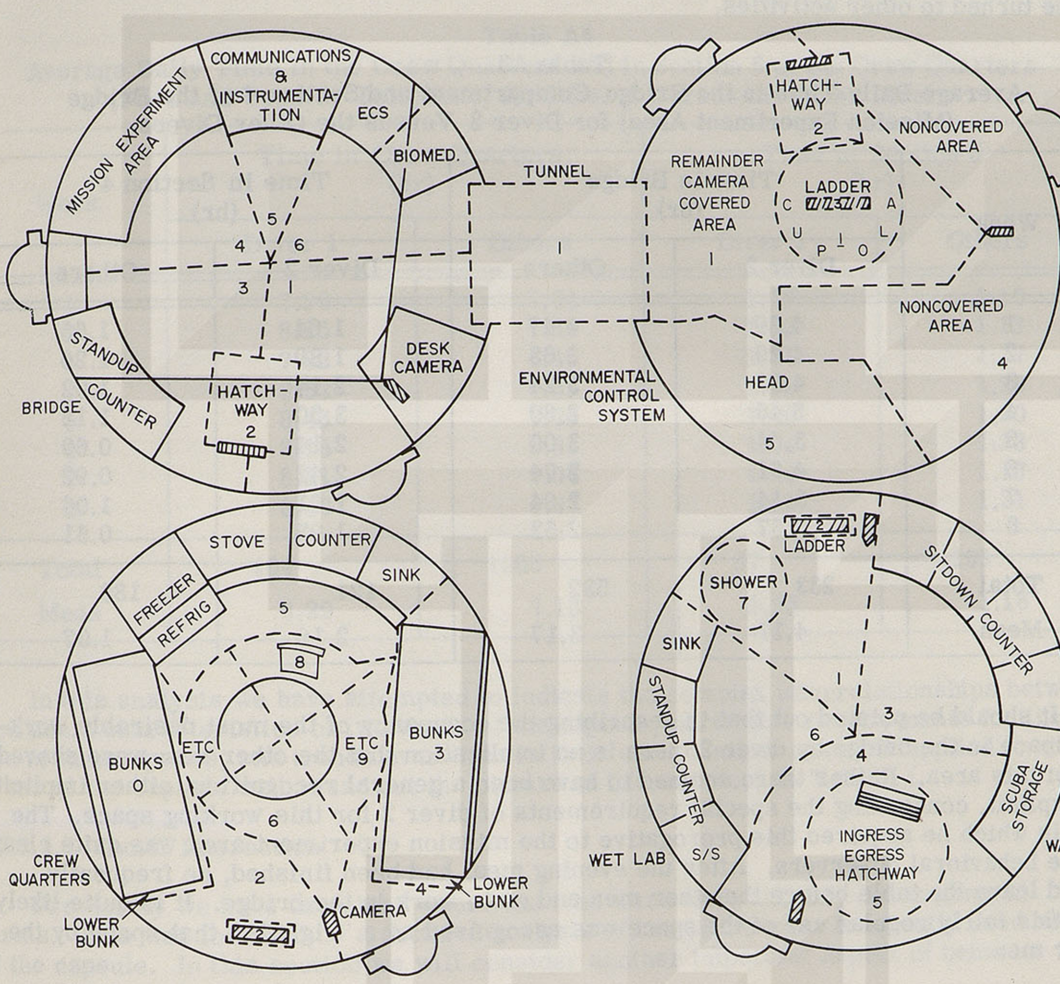

Fig. A5 - Habitat compartments and subdivisions mission mean level of 1 hour. During weeks 4, 5, and 6 his dominance in use of that particular section was quite marked; he spent as much time in section 4 during these three weeks as did all other men in the crew combined. During weeks 7 and 8 diver 2 devoted less time to the task requiring his use of section 4 in the bridge. During these last two weeks his use of this space fell off considerably over his heavy use during the middle of the mission. However, the other men did not increase occupancy of this space as he turned to other activities.

Table A3
Average Daily Time in the Bridge Compartment and Section 4 of the Bridge (Mission Experiment Area) for Diver 2 Versus the Other Divers

Week	Time in Bridge (hr)		Time in Section 4 (hr)	
	Diver 2	Others	Diver 2	Others
1	4.29	4.47	1.64	1.66
2	4.29	3.63	1.89	1.26
3	4.32	3.24	2.14	1.02
4	5.46	2.80	3.50	1.12
5	3.64	3.00	2.14	0.69
6	4.61	2.74	2.42	0.92
7	3.14	2.94	1.61	1.06
8	3.57	2.52	1.93	0.81
Total	233	532	121	180
Mean	4.17	3.17	2.16	1.07

It should be pointed out that in describing the occupancy of the most desirable working space in the bridge by diver 2 there is no implication that the other men were shoved out of this area. Rather there seemed to have been a general recognition, either implicit or explicit, concerning the special requirements of diver 2 for this working space. The way in which he acquired this prerogative to the mission experiment area was quite clear to the behavioral observers. After the evening meal had been finished, he frequently would leave the table before the other men and go to work in the bridge. It is quite likely that this fairly regular use of the space was recognized as a "right" to that space by the other men.

The next most heavily used area of the capsule was section 5 in the crew quarters (Fig. A5). This area was used with almost the same overall frequency as was section 4 in the bridge. It is not surprising that section 5 of the crew quarters was heavily used, since it contained the stove, counter, sink, freezer-refrigerator, and telephone for communicating with topside. The multipurpose nature of this area could explain why the man who used it most frequently did not dominate this area nearly to the extent diver 2 dominated the mission experiment area in the bridge.

The data for the use of the crew quarters and of section 5 in the crew quarters are shown in Table A4. The mean time spent in the crew quarters as a whole both for the man most frequently occupying those quarters and for the other three men as well was approximately double the time spent in the bridge area. Furthermore the time spent in section 5 of the crew quarters was a far smaller proportion of the total time spent in the crew quarters than was the time spent in section 4 of the bridge as a proportion of the total time spent in the bridge. The extra time spent in section 5 of the crew quarters by diver 1 was spent largely in talking to topside. Others in the crew spent as much or more time in section 5 either preparing for or cleaning up after meals as did diver 1. This diver 1 did not establish anything approaching territorial dominance either explicit or implicit over section No. 5. While diver 1 spent the greatest amount of time in this heavily trafficked area, the additional time which he spent there was very nearly the same during each of the eight weeks of the mission. That is, diver 1's time in section 5 of the crew quarters did not increase, as did diver 2's time in section 4 of the bridge.

Table A4
Average Daily Time in the Crew Quarters and in Section 5 of the Crew Quarters (Food and Topside Telephone) for Diver 1 Versus the Other Divers

Week	Time in Crew Quarters (hr)		Time in Section 5 (hr)	
	Diver 1	Others	Diver 1	Others
1	7.36	7.64	1.46	1.16
2	8.25	7.39	1.50	1.13
3	7.82	6.45	1.71	1.27
4	9.57	7.53	1.71	1.19
5	8.43	7.70	1.46	1.20
6	8.18	6.88	1.64	1.13
7	8.21	7.04	1.29	1.13
8	8.46	6.87	1.61	1.21
Total	464	1205	87	195
Mean	8.29	7.18	1.55	1.16

In this analysis we have attempted to indicate the complex interrelationships between functional characteristics of two areas of the capsule, particular requirements for the use of these spaces, and trends over time in their use. Similar analyses applied to other areas of the capsule will round out the picture of life and work in Tektite I.

A2.2.6.6 Social Interaction

Previously we have examined where the men were and what they did in general terms. This was followed by a detailed analysis of two of the most frequently used areas of the capsule. In this section we will consider another important aspect of behavior in Project Tektite I, social interaction.

The men did not act as individuals in a vacuum. Life and work were importantly influenced by their fellow team members. While at times the men worked and spent time alone, the majority of their time was spent with all four of the men together or in one of the many possible subgroups. Eleven possible group combinations were possible among the four men in the capsule: a tetrad (the group as a whole), four triads (any three men together, one man by himself), and six dyads (any two men together in one area; the other two men could be together in another area or separate in two other areas). In considering the Tektite I team as potential subgroups, it is apparent that even though we are dealing with a group of only four men, the total situation is highly complex.

An appreciation of the complexity inherent in the Tektite I team may be conveyed by noting that in any group of four men there exists 65 possible individual and group influences to be considered to describe the behavior of the men and the groups. We will not list all such combinations but cite examples to clarify what we mean. First, there are the personal influences on behavior in which each of the four men is considered as an individual. Next in level of complexity are dyadic influences, the effects of man A on B and of man B on A for all six pairs. In the four possible triads, it is necessary to consider the effects of individual A on pair BC and the effects of pair BC on individual A for all possible combinations. Finally, for the tetrad there exists the possibility of the influence of all four individuals on the four possible triads within the tetrad and their reciprocals plus the influences of all possible dyads on the other possible dyads. Add to this formidable array of within-group influences social interaction with persons outside the group and the situation appears to be one of bewildering complexity. The human social group may well be the most complex subject which science can aspire to analyze and understand.

This explanation of the complexity of social interaction may clarify several important aspects of the behavioral program. First, with regard to group composition, it should now be clear that the insertion of one group member into a crew, say a less-qualified or less-essential member for a more-qualified or a more-essential member, means far more than the addition or substitution of one crew member. It means a change in each and all of the subgroups of which the new person is a member, and it changes influences within those subgroups. This will be the case either if a member is substituted for another one in the group or if he is added to an already existing group.

Second, the above explanation may help to clarify the reliance on simple objective measures in the behavioral program. It would be impossible for a single observer, no matter how expert, to take in the group situation on a global level, to simultaneously perceive, comprehend, compare and synthesize the variety of interactions taking place at any one time, much less to do so over a long period of time. Thus, it was necessary to have many observers, all of whom collected similar data with a common frame of reference. Since these observers were of necessity relatively unskilled in collecting and interpreting behavioral data, it was necessary to use the simple straightforward objective measures. These systematically collected, quantitative measures of individual and group behavior then enable the researcher to understand the dynamics of the group by reconstructing it in the analysis phase of the study. It was the central thesis of the behavioral program orientation of Project Tektite I that the understanding of such group dynamics are best achieved by the collecting objective data relating to ongoing behavior of the group.

Third (a point of special relevance to this section of the report), not all subgroups or interactions are of equal importance. A systematic analysis of the data, guided by broad concepts regarding social interaction and understanding of the specific situation, will direct the attention of the investigator toward those relatively few relationships, out of the many possible relationships, which fit together in a meaningful fashion. One cannot study everything in an overwhelmingly complex situation. In the area of social interaction it is especially important to select carefully the behavior to be studied. It is also necessary to select carefully the behavior to be analyzed. At the time of writing this appendix the process of analysis had just begun for social interaction data on Project Tektite I. Therefore, this report will present only a few representative examples to illustrate the lawful relationships governing social interaction. The next section will be concerned mainly with dyadic interaction, examining the interrelations of various aspects of social interaction over time within the six dyads.

A2.2.6.7 Dyadic Interaction

The data in Table A5 present illustrative information on three aspects of dyadic interaction on Project Tektite I: time spent diving together, time spent together in the habitat, and the amount of time talking when men were together in the habitat as pairs. For our purposes a dyad is defined as two men together in the same compartment of the

Table A5
Correspondence of Dyadic Activities from 6:15 a.m. to 11:45 p.m.

Dyad or Pair	Diving Together		In Habitat Together		Total Together		Talking Together		Talking Together Relative to Time in Habitat Together	
	Time (min)	Rank	Time (min)	Rank	Time (min)	Rank	Time (min)	Rank	Per-cent	Rank
A	8	5	66	5	74	6	15	6	23	5
B	5	6	69	4	74	5	16	5	23	4
C	43	2	127	2	170	1	39	2	31	3
D	53	1	110	3	163	2	49	1	45	1
E	31	3	63	6	94	4	25	3	40	2
F	18	4	130	1	148	3	22	4	17	6
Av	26	—	91	—	117	—	28	—	31	—

habitat or in the water with the other two men elsewhere. Thus, two dyads could be formed simultaneously in different parts of the habitat, or one dyad could be in the water and one could be in the habitat, or one dyad could be in the water or the capsule with the other two men each off by himself.

There was a close correspondence between diving together, talking together, and being together in the capsule as dyads. This is especially true of the amount of time spent diving together and Talking. Table A5 presents the time spent in each of these categories on an average mission day. The average amount of time spent talking together and diving together for the total group over the entire mission are very nearly the same, 26 minutes for diving and 28 minutes for talking. For each dyad the amount of time spent talking together shows a close correspondence to the amount of time spent diving. This relationship is seen by comparing the rank numbers. Although the range of the distribution for time spent talking is less than for time spent diving, the ordering of the dyads is in almost exact correspondence, as is illustrated in Fig. A6. The ratios of time diving together are greater than 10 to 1 for the highest compared to the lowest pair.

The correspondence between the amount of time spent together in the habitat (Table A5) and the amount of time spent together diving as dyads is much lower than it is between diving and talking. Even though members of a dyad could spend considerable time in each other's company in the habitat, if they did not often dive together, they may have had relatively little to talk about. This situation could occur in a number of ways. If one pair were diving together, the other would be left in the habitat together and might be in the same space. Similarly if one pair had work to do together in the habitat, they might go to one compartment, leaving the other pair together in another compartment. However, the pair left together, almost by default as it were, was in a less than optimum social interaction situation. This appears to have happened in the case of dyad F. Note that although this pair is below average on diving time, they spent a greater amount of time together in the habitat than any other pair. However, the amount of time they spent talking is nearly equal in absolute amount to the time they spent diving. Furthermore, compared to other dyads on diving and talking, the two figures are in an equal relationship, both ranking fourth among the six dyads. As a result, the percent of time this pair spent conversing when they were together was the lowest of any dyad.

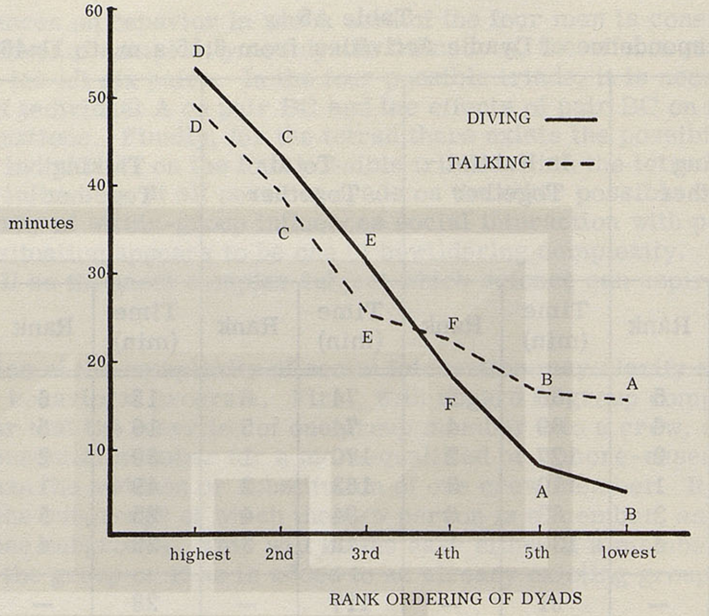

Fig. A6 - Consistency of the crew dyads in time diving together and talking together

The other major discrepancy between diving time and being together in the habitat is seen in the case of dyad E. This pair was above average in diving time, but they were the lowest in time together in the habitat. However, they ranked third in the amount of talking. Note that they spent more absolute time talking than did pair F, although they spent less than half as much time together. For dyad E, then, it appears that social interaction was voluntary. They got together as much as was required by their work together in the water and permitted by their activities in the habitat.

Thus we see in the data in Table A5 a strikingly close correspondence between diving time and conversation — a highly consistent relationship between work and social interaction. The apparent exceptions to the lawful relationship prove the rule. Two pairs, whose amount of time spent together as a dyad in the capsule was discrepant from the time they spent together in the water, used their social interaction opportunities in the capsule in a manner consistent with their work time in the water. In one case the amount of talking was markedly suppressed, and in the other it was enhanced.

Other data, not shown in tabular form here. document the formation and stability of dyadic interactions over the course of the mission. During the first 2 weeks of the mission there was little correspondence between diving and talking. Men who dived together most and least did not talk together most and least during this period. Furthermore, for both diving and talking the rank order of dyads on both variables shows little relationship to the rank order for the dyads for the total mission. That is, the men did not show clear preferences in either diving or talking during the first 2 weeks of the mission. Intragroup preferences were not clearly established until the third week. From the third week on, with minor exceptions, the patterns of interaction characterizing the total mission held steady until the end of the mission.

A2.2.7 Overview

In this report the conception and execution of the behavioral program on Project Tektite I has been presented along with illustrative examples of the results. We feel that the present report gives the most detailed objective account of the behavior of a group in a natural environment to date. Yet in two ways this report is only a beginning. First, extensive work remains to be done to complete the analysis of the present data. Second, this approach must be extended and applied to more as well as different natural groups to solidify and establish the psychological principles emerging from this work.

Further analyses of Project Tektite I data will extend and elaborate on the analyses presented here. Some other types of data not reported here will be added to the analysis. These other data include things such as times of arising and retiring, times of sleep, meal behavior, times of communications with topside, and data from the mood adjective checklist. Also, an analysis of interactions in the total group and in triads along with a great deal of additional work on dyads remains to be done. Much of the information in the present report, and the additional data to be analyzed, has yet to be synthesized and intercorrelated. Correlations and factor analyses are being applied to quantify the dynamic relationships between different aspects of the same man's behavior from day to day. The data obtained from Project Tektite I are capable of providing an account containing "clinical richness" hitherto available only on a global and impressionistic level. The advantage of the data from Project Tektite I is that the methods by which this rich account has been achieved are objective and scientific. That is, the data and analyses on Project Tektite I are independent of the unique experiences of the observers and interpreters, which is the opposite of the subjective clinical approach, where observations and interpretations are unique to the observer.

The second sense in which this report is only a beginning is in its report of the behavior of only a single group of four men. In response to this or even a more comprehensive report of the data on Project Tektite I a "so what" reaction is not unexpected. So we have data on the behavior of one group of men for 60 days. In response to such a reaction the authors would like to make two observations. First, this report presents more detailed behavioral data than has previously been available on any natural group. Second, the present methods can be applied to other groups to realize their potential. To know how specific men and groups spend their days, weeks, and months together, and to know it in detail, is a necessary first step toward a general understanding of adjustments to the environment in which their time is spent. The present methods, if used repeatedly, are capable of providing increasingly precise and lawful explanations of individual and group behavior. While it is important to collect information on other diving groups using the present techniques, it is even more important to extend the methods employed here to the measurement of behavior in other groups. An ideal opportunity for such an extension is the space program's proposed orbital workshop crews. While the exact opportunities and facilities are not available for studying space crews, the basic techniques can be adapted to that situation. Highly comparable data can be gathered on future undersea and outer space missions. Some advantages of this joint opportunity are the similarities of the men, crews, duration of missions, and psychological characteristics of the environments. Thus a number of variables affecting behavior are under natural control in that they are relatively equal. A common conceptual and methodological approach to data collection in the two environments will greatly accelerate the understanding of adjustment to and performance in both environments. Further, it is not necessary to limit the employment of the present methods to exotic environments. Many features of the methods developed on Project Tektite I can be used in the investigations of prosaic earthbound groups.

A topic of interest both to the present report and its extension to the future is the impact of the methods of measurement on the behavior being measured. That is, how reactive on Tektite I behavior were the measurement techniques used and what problems might be encountered in other environments? This is a question of considerable magnitude and will not be dealt with in detail here. However, a few relevant comments are appropriate.

In Project Tektite I, problems of reactivity were minimized in the collection methods employed, and reactions to the data collection methods were successfully controlled. This opinion is substantiated by subjective impressions based on observations and on objective data and comments from the aquanauts themselves.

The Tektite I crew appears to have adjusted quickly to being under constant surveillance. There were overt reactions to behavioral observation during the first few days in the form of hand-lettered signs and comments. Such overt reactions rapidly decreased, and throughout the bulk of the mission there were only occasional and universally good-natured verbal references to the "shrinks." These reactions stand in contrast to some pointedly negative reactions to actions that the crew regarded as unjust intrusions by operating personnel. These impressions gained during the mission were substantiated by postmission comments from the aquanauts themselves.

Objective indications of reactions to observation are provided by the number of times the TV cameras and the microphones were manipulated. Television was turned off on six different occasions, most of them relatively brief, less than 1 hour, to obtain privacy. The microphones, on the other hand, were turned off 54 times. These manipulations involved only one microphone each, with one exception, and again most of the interruptions were relatively brief. While in some cases there was a desire for privacy to discuss intimate personal topics, many of the manipulations of the microphones were directed toward operating personnel and not toward the behavioral program. Crew members wanted to discuss in critical vein their reactions to topside events without being overheard by the persons who were subject of the discussion. Thus the evidence indicates that microphones are more intrusive than is TV, the probable reason being that conversations are regarded as more private than is overt behavior.

Special efforts were taken to secure the cooperation of the Tektite I crew and to minimize their reactions to the behavioral observation program. Detailed explanations of the types of data recorded and the reasons for it were given to the crew prior to the mission. The men were all scientists and understood the importance of the behavioral program. Furthermore, it is likely that the objective nature of behavioral data made its collection acceptable to the men.

Since only four men were in the Tektite I crew, it was possible for the investigators to get to know them and to establish confidence and trust in the behavioral program and the way in which the data would be used. However, in future programs involving more men in which operations might become more routine, investigators may not be able to establish similar levels of confidence. If such is the case, the fact remains that some method of surveillance is necessary for the safety and the health of the crew. It is possible for behavioral observers to tap into such facilities. It is not necessary, though, to rely completely on facilities used for other purposes. There are a number of state-of-the-art methods of increasing the automation and decreasing the intrusiveness of behavioral data collection. Only insight, imagination, and money are required to make such methods operational. The possibilities in automating data collection can be appreciated by considering the sophistication which has been achieved in sensing and transmitting psychophysiological information. Surely, if it is possible to sense and transmit minute signals emanating from neurological or fine muscular responses, it should be a relatively simple matter to sense and transmit signals produced by gross muscular or whole body responses. Thus, for example, it should be feasible through the use of a variety of automated sensors to obtain records of location and activity similar to those obtained by observations on Project Tektite I. Such an application should be of special interest to the space program. The potential for increased automation indicates the final sense in which the behavioral program on Project Tektite I was only a first step in new directions.

A2.3 Sleep Patterns

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A2.3.1 Introduction

Loss of sleep and disturbed sleep have been observed in many studies which involved confinement of human subjects in hostile environments.* Although practical operational significance of sleep loss and disturbed sleep in field conditions is not clearly determined with respect to human reliability and efficiency, altered sleep patterns have resulted in performance decrement and undesirable psychological changes during the waking period under laboratory conditions.†

The primary purpose of the sleep research in Tektite I was to evaluate the quantity and quality of sleep of the aquanauts. Of particular interest was the possible effect of hyperbaric conditions on sleep and the relation of sleep patterns to waking activities.

A2.3.2 Procedure and Instrumentation

The sleep log of Hartman and Cantrell‡ was modified for use in this study. From the sleep log, which was scheduled to be distributed each day to all four aquanauts, the following information was obtained: duration of daytime nap, time of retiring and arising, trouble in going to sleep (on a four-point scale), how rested on awakening (on a

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*W. R. Adey, R. T. Kado, and D. O. Walter, "Computer Analysis of EEG Data From Gemini Flight GT-7," Aerospace Med. 38, 345-359 (1967); E. K. E. Gunderson, "Adaptation to Extreme Environments; Prediction of Performance," Navy Medical Neuropsychiatric Research Unit Report 66-17, 1966; R. W. Hamilton, J. B. MacInnis, A. D. Noble, and H. R. Schreiner, "Saturation Diving at 650 Feet," Ocean Systems, Inc., Tech. Memo. B-411, Mar. 1966; L. C. Johnson and M. T. Long, "Neurological, EEG, and Psychophysiological Findings Before and After Sealab II," Navy Medical Neuropsychiatric Research Unit Report 66-19, 1966; H. E. Lewis and J. P. Masterson, "Sleep and Wakefulness in the Arctic," Lancet 1, 1262-1266 (1957); G. C. Luce and J. Segal, "Sleep," New York, Coward-McCann, 1966; P. Naitoh, "Sleep Loss and Its Effects on Performance; Commentary and Bibliography," Navy Medical Neuropsychiatric Research Unit Report 68-5, 1969; P. Naitoh, R. Townsend, and M. Greenwood, "Sleep Requirements of Man-in-the-Sea," Navy Medical Neuropsychiatric Research Unit Report 68-22, 1969; J. T. Shurley, K. Natani, and C. M. Pierce, "Sleep Stage Patterns at South Pole," paper presented at APSS meeting, Boston, 1969; R. L. Maulsby, "Electroencephalogram During Orbital Flight," Aerospace Med. 37, 1022-1026 (1966); H. L. Williams, "Sleep Starvation and You," Army Information Digest, pp. 11-18, June 1964; E. S. Williams, "Sleep and Wakefulness at High Altitudes," British Med. J. 1, 197-198 (1959).

†N. Kleitman, "Sleep and Wakefulness," revised edition, University of Chicago Press, 1963; E. J. Murray, "Sleep, Dreams and Arousal," New York, Appleton-Century-Crofts, 1965; P. Naitoh, "Sleep Loss and Its Effects on Performance; Commentary and Bibliography," Navy Medical Neuropsychiatric Research Unit Report 68-5, 1969; R. P. Tucker, "A Review of the Effects of Sleep Deprivation," Univ. Michigan Med. Center J. 34, 161-164 (1968); R. T. Wilkinson, "Sleep Deprivation," pp. 399-430 in "The Physiology of Human Survival," O. G. Edholm and A. L. Bacharach, editors, New York, Academic Press, 1965; H. L. Williams, A. Lubin, and J. Goodnow, "Impaired Performance With Acute Sleep Loss," Psychol. Monogr. 73, No. 14 (whole No. 484) (1959).

‡B. O. Hartman and G. K. Cantrell, "Sustained Pilot Performance Requires More Than Skill," Aerospace Med. 38, 801-803 (1962); "MOL: Crew Performance on Demanding Work/Rest Schedule Compounded by Sleep Deprivation," USAF School of Aerospace Medicine Report SAM-TR-67-99, Nov. 1967.

four-point scale), today's mood (on a three-point scale), number of awakenings during the previous night, and need for more sleep (yes or no).

An electrophysiological recording system was assembled.* This uniquely stable and yet sensitive data acquisition system recorded two channels of EEG (left and right central derivations referenced to right and left mastoids), two channels of EOG (for monitoring eye-movements — left and right lateral canthi of eyes referenced to the right and left mastoids) and one channel for an electrocardiogram (EKG) (a sternal derivation).

The sleep data acquisition system consisted of two subsystems: one system was in the Tektite habitat, and the other was in the control van secured on the support barge. A harness electrode array with a quick-disconnect terminal was developed to lessen problems associated with attaching electrodes. The signals were amplified in the Tektite I habitat with Tektronix differential amplifiers, Type 2A61. The amplified single-ended biological signals were transmitted out of the habitat through a 1000-foot communication umbilical to the van. The Tektronix differential amplifiers were kept continuously on for 60 consecutive days and nights. In the control van two Beckman Type R dynographs (with six channels of Type 9806A dc/ac couplers and dual amplifiers Type 482M8 for each of Beckman recorders) received the transmitted biological signals and reconditioned and routed them to two folded vertical chart drives for ink recording on paper and to two Hewlett-Packard seven-channel FM instrumentation magnetic tape recorders, Model 3917B.

To synchronize paper and magnetic tape recordings and also to make computer retrieval of sleep data possible an IRIG compatible time code was generated by an Astrodata Model 5400 and recorded on both tape and paper. A Wavetek function generator, Model 110B, was left on in the Tektite I habitat and plugged into the amplifiers continuously, except the time when the aquanauts were using the amplifiers. A Wavetek function generator was set to feed calibrated 100-μV sinusoidal waves at 10 Hz into the data acquisition system, thus providing checks on electronic characteristics of the recording system. The shorted channel was added to the data acquisition system, so that any noises caused by ac power fluctuation and magnetic tape wow and flutter can be removed from the EEG recordings.

All-night recordings on two aquanauts, Edward Clifton and John Van Derwalker, were obtained as follows: every night for the first 10 days of underwater habitation (February 15 to February 24), every night for the last 8 days of underwater habitation (April 6 to April 13), and every Sunday and Thursday during the remaining period of underwater habitation. All-night recording was arbitrarily cut off at 7 a.m. The two aquanauts applied the electrodes to each other before retiring.

Two nights of sleep recording were obtained before and after Tektite I. The facilities of the sleep laboratory at the Navy Medical Neuropsychiatric Research Unit, San Diego, California, were used to obtain pre- and post-Tektite I sleep records.

A2.3.3 Results

A2.3.3.1 Sleep Log

The 60-day dive was divided into four 2-week periods: February 15-28, March 1-14, March 15-28, and March 29–April 15. The sleep log was not completed each day; the number of logs completed decreased for all aquanauts during the second half of the dive.

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*The assistance of Dr. Ralph Ritchie in designing this recording system is gratefully acknowledged.

Table A6
Selected Data from the Sleep Log

Subject	2-Week Period*	Trouble in Going to Sleep?*	Rested?†	Need More Sleep? Percent "Yes"	Mood‡	Number of Sleep Cards Used
Clifton	Feb. 15-28	3.46	2.91	100	2.0	11
	Mar. 1-14	3.00	2.83	100	2.0	12
	Mar. 15-28	3.14	3.00	100	2.0	7
	Mar. 29-Apr. 15	3.33	3.00	100	2.0	6
Manken	Feb. 15-28	3.50	3.13	63	2.3	8
	Mar. 1-14	3.46	3.09	91	2.0	11
	Mar. 15-28	3.86	3.29	43	2.0	7
	Mar. 29-Apr. 15	3.33	3.67	100	2.0	3
Van Derwalker	Feb. 15-28	3.90	3.00	50	2.3	10
	Mar. 1-14	3.18	3.55	13	2.0	11
	Mar. 15-28	3.00	3.20	0	2.0	5
	Mar. 29-Apr. 15	3.00	2.75	75	2.0	4
Waller	Feb. 15-28	2.17	2.67	100	2.8	6
	Mar. 1-14	3.64	3.18	82	2.7	11
	Mar. 15-28	3.00	3.00	100	3.0	2
	Mar. 29-Apr. 15	3.00	3.00	100	3.0	1

*4 (none); 3 (slight); 2 (moderate); 1 (considerable).
†4 (well rested); 3 (moderately rested); 2 (slightly rested); 1 (not at all).
‡3 (good); 2 (average); 1 (poor).

Table A6 shows the subjective evaluation of sleep as reflected from the sleep logs. The four aquanauts reported satisfactory sleep during the mission, experiencing no severe difficulty in going to sleep and waking up moderately rested. One of the aquanauts consistently reported he could have used more sleep, but he gave similar reports on pre- and post-Tektite I sleep nights. The first 2 weeks was the period in which one aquanaut reported more trouble going to sleep and all reported feeling less rested relative to the remainder of the dive. The fact that this was the period when watch schedules led to interrupted sleep was probably a factor.

Table A7 presents a summary of data for "time of retiring" and "time of arising." These data were collected by the behavioral observation team.* To evaluate the degree of agreement between the sleep logs and the data obtained by the behavioral observation team, product-moment correlation coefficients were computed between times of retiring and arising as recorded by the behavioral team and times of retiring and arising as shown on the sleep logs for each of four aquanauts. Correlation coefficients ranged from 0.994 to 0.997. A separate statistical test (t test) indicated no significant differences between the sleep logs and the report by the behavioral team with respect to times of retiring and arising. These findings suggest that the sleep log, when completed, was adequate for recording time of returning and arising and in estimating hours of sleep.

*We appreciated the excellent cooperation of Dr. Roland Radloff and his staff during the dive and for providing these data.

Table A7
Summary of Time of Retiring and Arising and Total Sleep Time
as Obtained by the Behavioral Observation Team

Period	Mean Time of Retiring		Mean Time of Arising		Total Sleep		Nap Time (hr)	Number of Sleep Cards		
	Time of Night	Std Dev (hr)	Time of Morning	Std Dev (hr)	Duration (hr)	Std Dev (hr)		Retiring	Arising	Total Sleep
Richard Waller										
Feb. 15-28	11:05	1.757	6:57	1.903	7.426	1.326	—	10	8	14
Mar. 1-14	11:06	0.950	7:49	0.469	8.735	1.012	—	14	13	14
Mar. 15-28	11:56	1.307	8:14	0.762	8.076	1.222	—	13	11	13
Mar. 29-Apr. 15	12:08	1.606	9:00	1.244	8.576	1.555	—	14	14	14
Eight weeks	—	—	—	—	8.205	1.363	7.1	—	—	55
Edward Clifton										
Feb. 15-28	11:25	1.447	6:50	1.738	7.161	1.473	—	11	11	14
Mar. 1-14	10:46	0.695	7:15	1.063	8.365	0.966	—	13	13	14
Mar. 15-28	11:40	0.731	7:53	1.014	8.256	0.919	—	14	14	14
Mar. 29-Apr. 15	12:10	1.170	8:01	1.108	7.877	1.259	—	15	15	15
Eight weeks	—	—	—	—	7.914	1.239	0	—	—	57
Conrad Mahnken										
Feb. 15-28	11:19	1.740	7:14	1.701	8.015	1.640	—	10	9	14
Mar. 1-14	10:16	1.122	7:17	1.111	9.005	1.294	—	13	13	13
Mar. 15-28	11:09	1.125	7:52	1.385	8.655	1.236	—	13	12	13
Mar. 29-Apr. 15	12:01	1.341	8:43	0.890	8.741	1.146	—	15	14	15
Eight weeks	—	—	—	—	8.598	1.354	4.6	—	—	55
John Van Derwalker										
Feb. 15-28	10:40	1.809	6:01	1.745	7.369	1.684	—	11	11	14
Mar. 1-14	10:18	1.175	7:09	0.867	8.713	1.179	—	14	12	14
Mar. 15-28	10:45	1.105	7:38	1.363	8.346	0.686	—	12	8	12
Mar. 29-Apr. 15	11:46	1.106	8:06	1.008	8.288	1.145	—	15	14	15
Eight weeks	—	—	—	—	8.175	1.306	2.3	—	—	55

Table A7 shows that the aquanauts averaged roughly 8 hours of sleep. Total sleep time during the first 2-week period was shorter than that during the remaining weeks. One of the aquanauts, Edward Clifton, on whom sleep records were collected pre- and postsaturation dive, slept longer hours during the dive.

The aquanauts went to bed progressively at a later hour. Analysis of data in Table A7 showed that the average retiring and arising times for the first 2-week period were 11:07 p.m. and 6:45 a.m. with a mean total sleep time of 7.5 hours. During the last 2 weeks the average retiring and arising times were 12:02 a.m. and 8:27 a.m., with mean total sleep time of 8.4 hours. The nap time varied for each aquanaut, with a high of 7.1 hours and a low of 0 hours over the 60-day period.

A2.3.3.2 Electrophysiological Patterns of Sleep

A2.3.3.2.1 Hand Scoring of Sleep Stages

The EEG sleep records of aquanauts Edward Clifton and John Van Derwalker were scored according to the sleep scoring manual of Rechtschaffen and Kales.* Twenty-two nights of scorable records were obtained from John Van Derwalker, and 32 nights of sleep records were obtained from Edward Clifton. Table A8 shows the summary of some of the critical sleep parameters, together with normative sleep data obtained by Webb and Agnew.†

The data shown in Table A8 indicate no dramatic changes in the proportion of time spent in the various sleep stages during hyperbaric nitrogen saturation, except perhaps that the aquanauts spent more time in slow-wave sleep (the sum of sleep stages 3 and 4).

A2.3.3.2.2 Analog Computer Analysis of Sleep EEG Data

In visual scoring of sleep stages, all 2-Hz or slower brain waves which exceed 75 μV are handled identically, regardless of actual amplitudes. Visual inspection of sleep records during the dive suggested that the delta waves during slow-wave sleep were very high in amplitude, indicating some possible alteration of "intensity" of slow-wave sleep. To obtain absolute intensity of the delta EEG activity during sleep, an analog computer (Systron-Donner 10/20) was programmed to compute the envelope of squared voltage of bandpassed brain waves of 1 to 2 Hz with an electronic filter.‡ Details of the analog computer analysis and the results will be made available in a separate report. The rhythmicity of the REM-non-REM cycles will also be obtained from this analysis.

A2.3.3.2.3 Digital Computer Analysis

Under an Office of Naval Research contract, S. Viglione of Astropower Laboratories, McDonnell-Douglas, will apply his pattern recognition technique to the tape-recorded sleep data to obtain automatic EEG staging of sleep.§ The details of methods and results will also be made available in a separate report.

A2.3.3.2.4 Analysis of EKG Data

The EKG data obtained during Tektite I habitation will be analyzed by generating frequency histograms of heart rate (sleep stage 2 only) with a Computer of Average Transients (CAT 400C) plus additional hard-wired instrumentation. The details of method and results will be made available in a separate report.

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*A. Rechtschaffen and A. Kales, editors, "A Manual of Standardized Terminology, Techniques and Scoring System for Sleep Stages of Human Subjects," U.S. Government Printing Office, Washington, D.C., 1968 (NIH Publication 204).

†W. Webb and H. W. Agnew, Jr., "Measurement and Characteristics of Nocturnal Sleep," pp. 2-27, in L. E. Abt and B. F. Riess, editors, "Progress in Clinical Psychology," Vol. 8, New York, Grune and Stratton, 1968.

‡D. F. Caldwell, "Differential Levels of Stage IV Sleep in a Group of Clinically Similar Chronic Schizophrenic Patients," paper presented at the 23rd meeting of the Society of Biological Psychiatry, Washington, D.C., June 16, 1968.

§D. B. Drane, W. B. Martin, and S. S. Viglione, "The Application of Pattern Recognition Techniques to the Scoring of EEG Sleep Patterns," paper presented at APSS meeting, Boston, 1969.

Table A8
Comparison of Sleep Stages of John Van Derwalker and of Edward Clifton with a Base-Line Sample of 12 Adult Males, 30-39 Years Old, Obtained by Webb and Agnew

Time Period	Total Sleep Time (min)	Total Wake (%)	Total Sleep (%)	Stage 1 Sleep (%)	REM (%)	Stage 2 Sleep (%)	Stage 3 Sleep (%)	Stage 4 Sleep (%)	Time to First REM (min)	Number of Nights
John Van Derwalker										
Predive	420	1	98	7	25	52	4	9	82	2
Feb. 15-19	390*	1	99	4	26	48	10	11	52	5
Feb. 20-24	399*	2	98	4	27	44	10	12	57	5
Mar. 23, 27, 31	373*	2	97	4	24	46	10	13	126	3
Apr. 8-9	474*	0	99	2	25	53	12	8	119	2
Apr. 10-13	368*	1	98	5	28	45	10	10	73	3
Postdive	394	2	98	3	32	44	7	12	46	2
Base-Line Sample										
–	443	2	98	8	22	53	5	10	100	–
Edward Clifton										
Predive	384	10	89	5	21	45	7	10	129	2
Feb. 15-19	366*	1	98	4	22	43	13	17	106	5
Feb. 20-24	360*	2	96	5	19	45	12	15	139	5
Feb. 27; Mar. 6, 9, 13, 16	437*	1	97	3	22	54	7	12	82	5
Mar. 20, 23, 27, 31; Apr. 3	426*	1	97	5	20	50	10	13	101	5
Apr. 6-9	390*	1	98	4	24	47	12	11	73	4
Apr. 10-13	376*	1	99	3	19	56	7	14	93	4
Postdive	351	0	98	6	21	43	9	19	133	2

*From retiring to 7:00 a.m.

A2.3.3.2.5 Relation to Waking Behavior

To enable a correlational study between sleep quality and efficiency in waking activities, a quantitative index of "goodness" of sleep was developed. The details of this analysis will be made available to the behavioral team after it is completed.*

A2.3.4 Discussion

Preliminary analyses of sleep data from both the sleep logs and electrophysiological recordings indicated that the aquanauts experienced no severe sleep loss or disruption of sleep cycles during Tektite I. Instead of obtaining less sleep the aquanauts appeared

*EEG sleep recordings were made on Richard Waller during the first 10 days and last 8 days of the dive by a NASA research team headed by Milton DeLucchi. These data will be reported in a separate paper.

to have slept longer and deeper. Even though their sleep was longer, they generally desired more sleep, suggesting that more than their usual amount of sleep was required. The reasons for this increased sleep need are not clear; it could have been caused by the vigorous excursion dives,* by the effect of hyperbaric nitrogen saturation, or as a result of the absence of rigid time schedules for retiring and arising† and probably by other undetermined factors.

Time of retiring shifted progressively toward a later hour with a consequent shift in time of arising. The aquanauts were aware of the altered time of retiring and arising, and they attempted to go to bed earlier so that they could wake up earlier and use the early morning hours for excursion dives. Yet they persisted in retiring later despite their manifest wish to do otherwise. Similar shift in times of retiring and arising was reported by Webb and his associates under a condition of sensory isolation (personal communication).

The two aquanauts who were electrophysiologically monitored for sleep gave EEG evidence of longer and deeper sleep. Since electrophysiological sleep recordings were cut off roughly at 7:00 a.m., and the aquanauts continued to sleep on occasions 1 hour or more, we do not have recordings of complete sleep. Usually this morning sleep consists of sleep stages REM, 2, or 1. Thus, our computed values of proportions for each sleep stage (Table A8) would tend to underestimate proportions of REM, 2, and 1 and to overestimate somewhat the proportion of slow-wave sleep. For this reason, and because of the limited number of recordings, we must regard our finding of increased slow-wave sleep in these two aquanauts as tentative.

The finding that the aquanauts slept longer and desired more sleep during Tektite I poses some logistical problem in planning future underwater habitation. First, there is increasing evidence indicating that excessive sleep may be detrimental to waking performance. Subjects generally tend to feel groggy when sleeping in excess of their usual amounts.‡ Thus excessive sleep rather than sleep loss may be a major problem. Second, with the increased time asleep, work efficiency will have to increase to compensate for the shorter work hours. Third, research should be undertaken to determine whether the hours of sleep are crucial and, if so, whether the sleep could be shortened by imposition of a more rigid schedule of retiring or arising or whether the efficiency of sleep can be increased. How and if the latter can be achieved is a question for study on its own.

The absence of sleep difficulties contrasted with the majority of reports on sleep under hostile environments, which have reported sleep loss and disturbed sleep. Tektite I was the first long-term confinement experiment under hostile environment in which the subjects showed no significant sleep problems. Reasons for the absence of sleep difficulties could be many. The fact that the aquanauts maintained an ad lib type of work/rest schedule, the fact that the habitat design excluded excessive noise in the crew quarters, and the motivation and emotional stability of the aquanauts were probably important factors.

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*F. Baekeland and R. Lasky, "Exercise and Sleep Patterns in College Athletes," Percept. Motor Skills 23, 1203-1207 (1966); G. A. Leinert and E. Othmer, "Objective Correlates of the Refreshing Effects of Sleep," Prog. Brain Res. 18, 170-174 (1956); J. A. Hobson, "Sleep After Exercise," Science 162, 1503-1505 (1968).

†E. A. Aluisi, W. D. Chiles, and R. P. Smith, "Human Performance in Military Systems: Some Situational Factors Influencing Individual Performance," Performance Research Laboratory, Department of Psychology, University of Louisville, Louisville, Kentucky, Aug. 1964.

‡G. G. Globus, "Sleep Duration and Feeling State," in E. Hartman, editor, "International Psychiatric Clinics," Boston, Little Brown; J. M. Taub and R. J. Berger, "Extended Sleep and Performance: the Rip Van Winkle Effect," Psychonomic Science 16, 204-205 (1969).

The absence of sleep difficulties encourages us to take a closer look at the subjectively reported difficulties in sleep encountered in deeper ocean floor excursion under helium-oxygen saturation dives.* The findings from Tektite I suggest that sleep disturbances and sleep loss under helium-oxygen saturation dives may not be caused by living under water per se. Tektite I sleep data suggest that man can adapt to nitrogen saturation and live on the ocean floor for productive work.

A2.3.5 Summary

Sleep logs and electrophysiological recordings were used to evaluate the sleep patterns of the aquanauts in Tektite I. Sleep logs were completed by all four aquanauts; all-night EEG recordings were obtained from two aquanauts. Comparison with the data made available by the behavioral observation team indicated that the sleep log was accurate in reporting times of retiring and arising and in estimating the hours of sleep. Analyses of sleep log and electrophysiological data indicated that the aquanauts did not have major sleep difficulties. They slept for longer hours (8 plus hours) and stayed in deeper sleep (slow-wave sleep) for a longer time during the dive period. The absence of sleep difficulties and increased need for sleep have implications in terms of future dives under nitrogen or helium saturation.

A2.4 Automatic EEG Acquisition and Data Analysis System
M. R. DeLucchi, National Aeronautics and Space Administration, Manned Spacecraft Center, Houston, Texas, and J. D. Frost, Jr., and P. Kellaway, Baylor College of Medicine and the Methodist Hospital, Houston, Texas

A2.4.1 General Description

A2.4.1.1 Introduction

In the last 3 years a number of component assemblies have been developed, under NASA contracts, which are related to acquisition and analysis of EEG data. Specific interest in the EEG focuses upon its critical role in the evaluation of neurophysiological alterations associated with sleep/wake states. Examination of the biomedical results of the Mercury, Gemini, and Apollo series indicates that sleep and sleep/work cycles are significant factors in manned spaceflight. It may be anticipated that increase in flight duration and lunar surface exploration will perpetuate the importance of the phenomenon of sleep and may well accentuate its role in successful mission accomplishment.

Tektite I provided an opportunity to operationally test a prototype system specifically directed toward the task of monitoring and evaluating sleep during manned spaceflight. Because of potential future development as flight-qualified items, it was required that the prototype components be significantly reduced in size from those conventionally utilized in the clinical laboratory. It was decided to attempt to record, and analyze on-line, the sleep patterns of one member of the Tektite I crew during the initial 10 days and again during the final 10 days of the 60-day mission.

Three basic subassemblies were to be evaluated: an EEG-EOG-EMG electrode cap, preamplifier and tape-recorder systems, and an automatic EEG sleep analyzer. The

*R. J. Hock, G. F. Bond, and W. F. Mazzone, "Physiological Evaluation of Sealab II: Effects of Two Weeks Exposure to an Undersea 7-Atmosphere Helium-Oxygen Environment," Deep Submergence Systems Project, U.S. Navy, Dec. 1966; R. Radloff and R. Helmreich, "Group Under Stress: Psychological Research in Sealab II," New York, Appleton-Century-Crofts, 1968.

answers to a number of specific and practical questions were sought with respect to each subassembly, but with particular regard to the way in which the components performed as part of the complete system.

A2.4.1.2 Electrode Cap

The electrode cap assembly was designed to permit detection of EEG, EOG, and EMG activity from the head of the subject. Recording of such electrical activity in prolonged extralaboratory situations, especially when the observer cannot have direct physical contact with the subject, requires several modifications of the usual methodology. The electrodes must be easily applied by the subject himself and with little loss of time. They should be accurately but automatically positioned to ensure reliability of data. The electrodes must be durable and not easily dislodged by pulling, motion, or scraping. They should not be susceptible to movement artifact. Damage, irritation, or maceration of the skin cannot be tolerated because of the risk of infection. Finally, the array must be comfortable, even while the subject is sleeping or attempting to fall asleep. Evaluation of the electrode cap with respect to these requirements during the Tektite I project will provide useful insight into the proper directions for further development.

A2.4.1.3 Preamplifier and Tape-Recorder Assemblies

The Gemini series EEG preamplifiers had been extensively tested in laboratory situations and were known to perform well even with the relatively high interelectrode impedances presented by the electrode cap. The susceptibility to extraneous electrical interference was not so well known, however, and the conditions of the Tektite I experiment, where recording was to be carried out in the subject's unshielded bunk in close proximity to other equipment, would provide a good test of this aspect.

A new series of EEG preamplifiers, developed for the Apollo program, were also included in the system to allow comparison and evaluation of improvements in noise rejection as well as any adverse effects of the environmental situation (increased atmospheric pressure) upon the electrical characteristics.

The reliability of the long-term magnetic-tape-recording system developed during the Gemini program would also be evaluated, as would the quality of the recorded data.

A2.4.1.4 Automatic Sleep Analyzer

The automatic sleep analyzer has been developed to permit continuous, automatic, on-line evaluation of a subject's state of consciousness. Its use during Project Tektite I will permit an evaluation of its reliability under circumstances when the sleep periods might be expected to be altered because of unusual stresses and working conditions. The influence of unsuspected artifacts or environmental conditions will also be of importance in further development of the system.

A2.4.2 Equipment

A2.4.2.1 Electrode Cap

The electrode cap developed by W. R. Adey* and tested by P. Kellaway† was used with only minor modifications during the initial 10-day recording period. Further changes which became necessary in the electrode system will be detailed in section A2.4.3.

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*W. R. Adey, "Development of an Electrode-Amplifier-Harness System for Physiological Data Acquisition," final report, NASA contract NAS 9-7282.

†P. Kellaway, "Development of an Electrode-Amplifier-Harness System for Physiological Data Acquisition," NASA contract NAS 9-7237.

As illustrated in Figs. A7 and A8 the electrode cap contained six conventional EEG electrodes (F_1, F_2, C_3, C_4, O_1, O_2), two EOG electrodes (left outer canthus and central forehead), and two neck EMG electrodes, in addition to a ground located near the vertex. Also visible in Fig. A7 are foam-rubber pads, which were added in the posterior region of the head to increase comfort.

The scalp side of the electrode-cap assembly is demonstrated in Fig. A9, and the silicone-rubber sponge contacts are visible. These foam-rubber contacts were presaturated with an electrolyte gel, and, as indicated in Fig. A10, were easily replaced by the subject. An exploded view of one of the cap electrodes is shown in Fig. A11 beside an assembled electrode. An Ag/AgCl pellet is contained in the clear plastic plug, which also supports the amplifier lead cable. This component fits into the silicone-rubber housing molded into the fabric of the cap. The housing also accepts the foam-rubber sponge as illustrated in Fig. A10. The complete electrode assembly is approximately 3 cm long. The material of the cap itself is elastic (Lycra), and thus a constant light pressure is exerted on the electrodes, maintaining contact between the foam-rubber sponges and the scalp.

Fig. A7 - Electrode cap worn by aquanaut

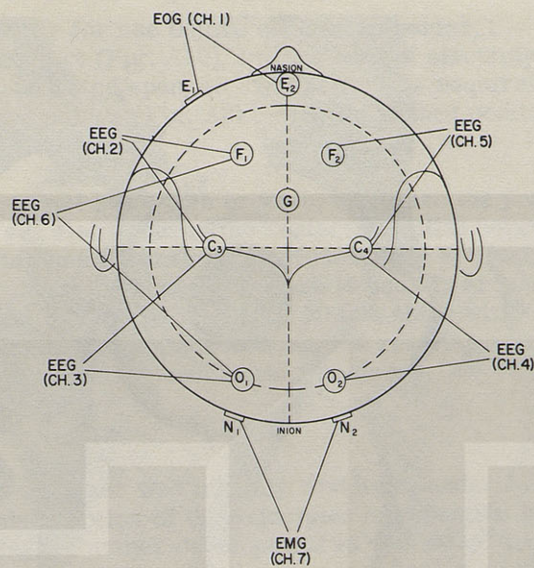

Fig. A8 - Montage used during the first ten recording nights

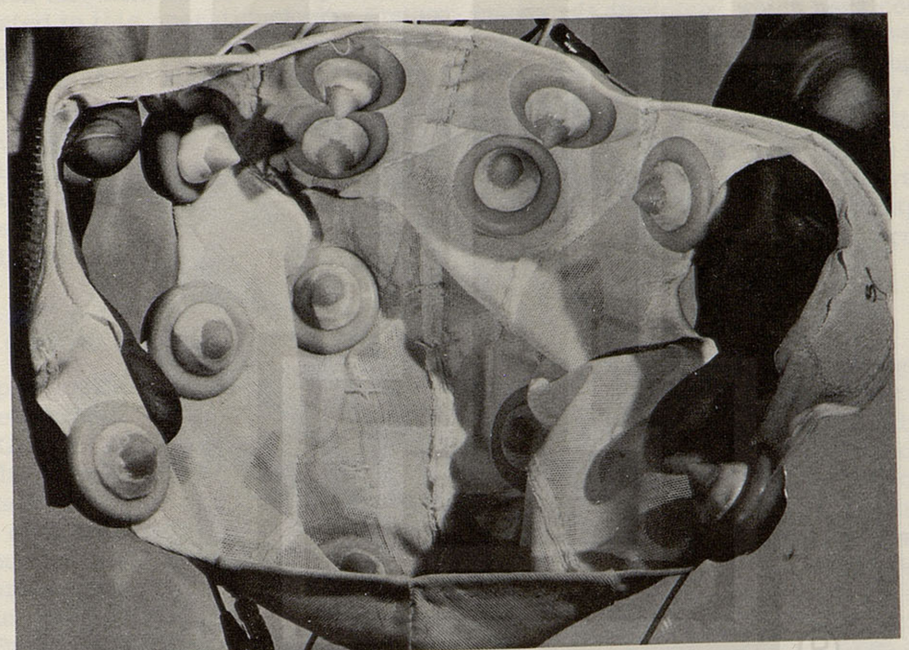

Fig. A9 - Scalp view of electrode cap

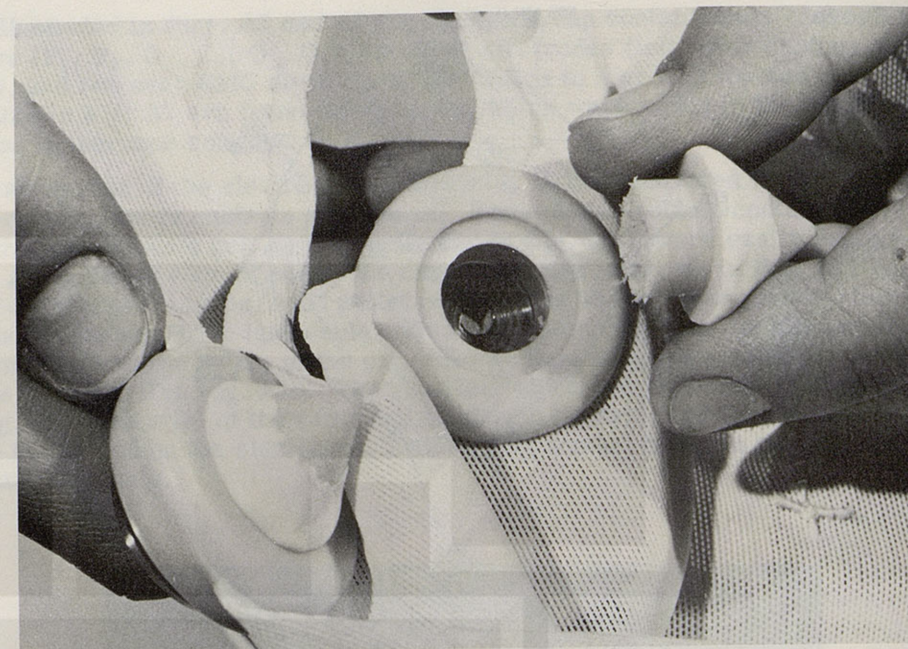

Fig. A10 - Two electrodes on the cap: one is shown with the sponge contact removed

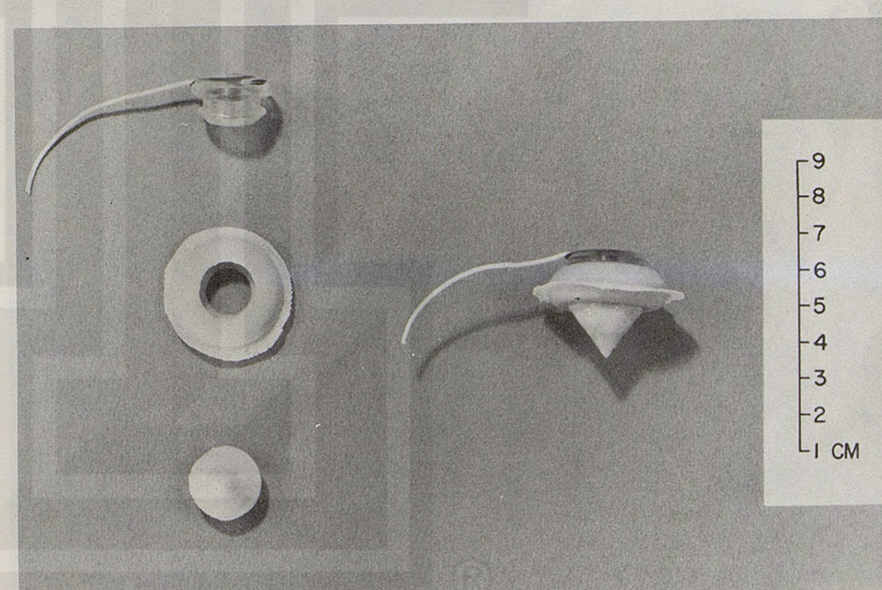

Fig. A11 - Exploded view (left) and assembled view (right) of a single electrode. The clear plastic plug (upper left) contained an Ag/AgCl pellet, and the foam rubber contact (lower left) was presaturated with an electrolytic gel before each sleep period.

To prepare the assembly for use before each sleep period, the subject removes and discards the old sponge contact (Fig. A10), injects 1 ml of electrolyte gel into the housing, and reinserts a new, presaturated sponge. This procedure requires approximately 10 minutes for the electrode montage (Fig. A8). The cap is then positioned on the head and secured with a padded chin strap.

An isotonic electrolyte gel is used in order to minimize the possibility of skin irritation and infection. This gel also reduces the contact potential between body fluids and electrolyte and thus diminishes the magnitude of electrical artifacts associated with movements of the head. Interelectrode resistance is usually around 100,000 ohms when the cap is first donned, but this drops to around 30,000 ohms within a few minutes. However, even after 8 to 12 hours of continuous wear, the resistance is usually still 20,000 ohms, indicating preservation of the usual skin resistance.

A2.4.2.2 Automatic Sleep Analyzer

The automatic sleep analyzer was initially developed under NASA grant NGR-44-003-025, and a detailed description of the principles of operation is contained in the final report submitted to NASA.* Further development is underway† to adapt this system for on-board EEG analysis and evaluation of sleep/waking cycles during manned spaceflight.

The general approach has been to determine the minimum amount of EEG and EOG information actually needed to make a proper decision and to determine the most direct way in which this information can be automatically extracted from the total EEG. The system tested in this operational situation is a laboratory prototype which uses conventional transistorized circuitry, occupies about 1-1/2 cubic feet of space, and provides an output in terms of the standardized clinical stages of sleep (awake, stages 1 through 4, and REM). The system is essentially an amplitude-weighted, dominant-frequency meter for the EEG bandwidth (0.7 to 14 Hz), with the output restricted to six distinct voltage levels. Since the device considers essentially the same criteria as those used in visual scoring (a combination of dominant frequency and amplitude), the results are in very close agreement with those of expert visual interpretation. An example of the output is provided in Fig. A12, which shows the sleep pattern for the aquanaut during project night 50.

A2.4.2.3 General Scheme of the Operational Situation

The physical locations and interconnections of the data acquisition, recording, and analysis equipment are indicated in Fig. A13. Within the Tektite I undersea habitat, the EEG, EOG, and EMG activity was detected with the electrodes of the cap assembly, and the signals were led to preamplifiers. Seven channels (five EEG, one EMG, and one EOG channel) were amplified by the Gemini series NASA preamplifiers (Beckman) and recorded on a miniature magnetic-tape recorder (Cook/NASA) located near the subject's bunk. Four channels (three EEG and one EOG channel) were also led from the cap to Apollo series preamplifiers (Spacelabs) and transmitted to the surface monitoring van. Within the monitoring van the data were displayed at selected paper speeds on a four-channel Brush graphic recorder and simultaneously recorded on a conventional magnetic-tape recorder (Ampex SP300) at 1-7/8 inches per second (this served as a backup system to the recorder in the undersea habitat). One EEG channel and one EOG channel entered the automatic sleep analyzer, and the results of the electronic analysis were displayed on the two-channel graphic recorder (Brush) as illustrated in Fig. A12.

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*P. Kellaway, "An Electronic EEG Sleep Analyzer," NASA Grant NGR-44-003-025.
†J. D. Frost, Jr., "Development of a Prototype Onboard EEG Analysis System," NASA contract NAS 9-9418.