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"I am convinced that the main goal for the future of underwater exploration is not the discovery of new resources, but the discovery of new sources of inspiration. And, of course, we need better submarines, better lungs, better filling mixtures, but above all, we need scientists to understand, and poets, painters, architects, philosophers to express it. We need a thousand new words which have to be forged by imaginative people. We need to reform our way of thinking about the sea. We need to return to the sea."

Jacques-Yves Cousteau
Presidential Address
World Underwater Federation
1964 Convention

Larry Raffety
School of Architecture
Montana State University
November 13, 1972

Thesis Proposal:

An exercise encompassing the design of an
undersea research facility -

will involve the collection and use of data
defining the characteristics of inner space

will involve the investigation of psychological
and physiological requirements of men living in
alien surroundings, as well as the structural
and mechanical ramifications thereof

will result in the acquisition of knowledge
concerning man's last earthbound frontier, and
the architectural exploration of that knowledge

seeker



P378
R1225

~~140.6~~ ~~NA2070~~
~~M76~~
~~R123~~

Thesis Committee:

William S. Semple - chairman
Assistant Professor of Architecture
School of Architecture

George S. McClure, Jr. - Advisor
Associate Professor of Architecture
School of Architecture

William D. Bliss - Advisor
Head and Professor of Psychology
Department of Psychology

more resource people may be added as required

The project also entails extensive help from
federal and private agencies or organizations
concerned with undersea exploration.

Larry Raffety
School of Architecture
Montana State University
January 10, 1973

As stated in my preliminary thesis proposal, I wish to undertake an exercise encompassing the design of an undersea research facility - a facility recognizing the knowledge and experience gained through recent projects of similar nature while concurrently reaching out for new ideas and concepts of undersea living and working. I am undertaking this exercise assuming that human life can successfully function in direct extended contact with the ocean world.

I will not be prepared to produce a more detailed description of the project until further investigation and organization of accumulated research material has been completed. It must be realized that this project's very roots lie in an idea without contemporary prototypes. Preceding undersea habitations have obviously been too few in number to have explored many possibilities, besides being predominantly concerned with discovering and understanding how or if human life could successfully function in the sea for extended periods of time. I believe you can thus understand how perhaps a greater portion of this project's determinants must follow extensive research.

The following page is a gauge of current progress with an envisioned time-table for the entire project.

seeker



idea formation

September

October

collection of research material

November

November 13, 1972

submission of preliminary proposal
investigation of research material

December

January

January 10, 1973

submission of further detailed proposal
definition of size and scope of project

February

organization of research material

March

March 9, 1973

completion of basic program
formation of preliminary concepts
presentation of progress report

April

culmination of major design work

May

perfection and public presentation of work
extensive documentation of all phases
of project

June

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The project also entails extensive help from federal and private agencies or organizations concerned with undersea exploration.

I have arranged a weekly meeting with Bill Semple for the beginning portion of this quarter. This arrangement will change as the quarter progresses, as will the present sporadic contacts with my other advisors.

I would strongly suggest that the members of the school's thesis committee read Jacques-Yves Cousteau's World Without Sun, which I will make available to you. This book of general interest should give you a familiarity with the type of project I am undertaking.

Larry Raffety
School of Architecture
Montana State University
February 5, 1973

Before undertaking the investigation of various systems and spatial arrangements, an effort must be made to define the objectives having the most marked effect upon the material to be investigated. That is the sole purpose of this paper.

Seeker: goals, scope, capacities

I. Occupants:

The number of occupants and the major concerns of each should fall on or between the following:

1 engineer	2 engineers
1 pilot-engineer	2 pilot-engineers
1 health specialist	1 health specialist
1 cook-custodian	1 cook-custodian
8 scientists	10 scientists

The major objective should be to sustain as many scientists as possible with as few support personnel as possible. The number of engineers will thus be a direct result of the simplicity and operational requirements of the facility.



II. Mobility:

The facility should be capable of traveling at will under its own power. This admittedly will add greatly to the facilities complexity

and cost - but these are offset by the need for no surface vessel(s), the ability of the facility's scientific personnel to undertake research requiring movement, and its much greater productive life as a result of the capability of engaging in research at any location without extensive between-mission delay.

Such things as simplicity, ease of operation, and small-volume high-efficiency fuel should be paramount concerns in the design of movement systems.

III. Depth-time range:

As this facility is to be concerned primarily with the continental shelf, a maximum depth of 1000 ft. is to be designed for. Storage and other time limited systems are to be designed for a 90 day period without resupply.

IV. Support systems:

All life support systems should be as self-contained as possible. Any resource taken from the surrounding water should be either fully consumed or returned in its natural state. It would be ideal if no waste of any kind were rejected into the surrounding water.

An investigation should be made into the feasibility of a deployable surface buoy which would assist in the operation of some systems when the facility is not in transit.

A supply vehicle capable of travel to and from surface or land-based supply centers should also be investigated.

Since this facility will have no sister support vessel at the surface, decompression should take place in the facility itself.

V. Auxiliary equipment:

The following should all be investigated as possible auxiliary equipment:

- supply vehicle
- small exploratory submarine
- diver assistance vehicles
- deployable way stations

Means must also be provided for the storage and transport of equipment, related to scientific studies, which will eventually be deployed or used in the surrounding waters.

VI. Emergency systems:

Emergency systems should be designed to sustain the facility for one to two weeks.

The feasibility of a self-surfacing emergency support module should be investigated. This module would be capable of transporting the crew to the surface at facility pressure, and subsequently undertaking decompression while waiting for surface rescue.

As is probably obvious by now, this facility's concept is based on totally independent operation, free of any link, excepting communication, with any one else.

orientation

a concise familiarization
with the undersea environment

inhabitants

physiological attributes
psychological attributes
sociological attributes

operations

connections
sequences
patterns

facilities

structure
materials
power
life support
movement
safety
communication

orientation

inhabitants

This portion dealt with the problem of enabling people not directly involved with the project to understand major attributes and design implications of the sea. It was presented in approximately eighty slides covering the following areas:

- geography
- waves/currents

- life above water

- life on the surface

- life in upper waters

- life in open waters

- life in bottom waters

- corals

- survival

- life in deep waters

- light/color

- sound

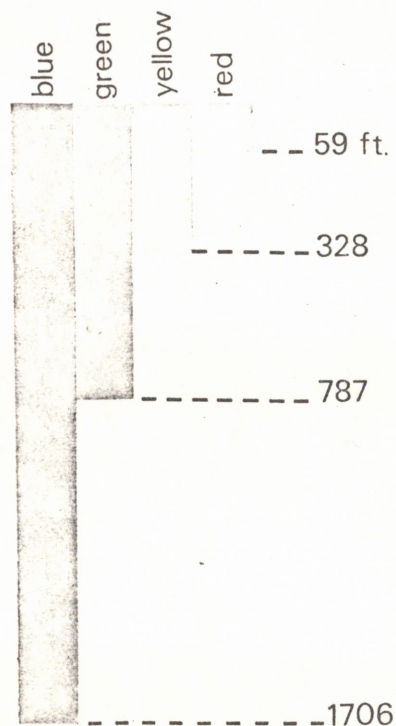
- pressure

- brief history of undersea
exploration

Physiological Attributes

Sense/Sight

Visible light is composed of electromagnetic radiation ranging from the longer wavelengths of red through orange, yellow, green, to the shorter wavelengths of blue. Water absorbs these different wavelengths at different rates. Longer wavelengths of light, such as red and orange, are absorbed most rapidly. For example, the red portion of the visible spectrum is reduced to ten percent of its surface intensity at a depth of fifteen feet. A red object below the point where all red light was absorbed would appear basically as black. The shorter wavelength colors penetrate deeper. The following diagram illustrates this, and is based on measurements taken by William Beebe from his bathysphere off the Bermuda coast --- in extremely clear water. His observations: red light faded into nothingness at 59 feet, yellow within 328 feet, green within 787 feet, and blue gave way to pitch black at 1706 feet.



Although the color of the sea itself is often blue, this color changes to reflect the color of the sky. The pigments of plankton and suspended sediments also change the color of the sea.

The distance and clarity of human vision underwater is proportional to the amount of sediment present in the water, and the depth at which one is working. Visibility can approach zero in extremely cloudy water, and artificial light is so greatly reflected from suspended particles that its effectiveness is reduced considerably. At pitch black depths artificial light can be effective provided the water is relatively clear.

Unevenly distributed sediments displaced by underwater wave motions may cause wavyness of what a diver sees.

Color can be used to gain various results within the habitat. Light pastels will make spaces appear larger. Contrasts are important for gaining a lively, variable atmosphere, as well as for definition and differentiation. Color intensity can also be used as a varying element. Light intensity, shade and shadow can be used for definition and variety. Colors can impart differing senses of temperature and activity.

Marine life presents the visitor with an endless array of color --- even in the deepest parts of the oceans where sunlight never penetrates. Many undersea organisms produce their own light --- such as the bioluminescence produced by thousands of microscopic organisms known as dinoflagellates. Deep sea creatures produce a similar light, through chemical processes, of various colors and intensities. Various seeing mechanisms have evolved in marine life --- from the shallow water creature's eyes very similar to those of land mammals, through the

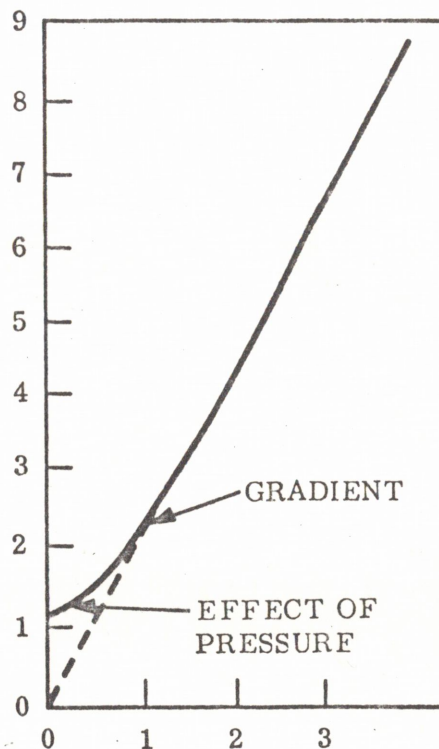
telescopic vision of mid depth fish, to the complete blindness of inhabitants of the deepest waters. Change of color patterns is often used as a disguise against natural enemies, as is the expulsion of opaque liquids to escape behind.

Artificial light seems to have no major detrimental effects, when from a stable source, on marine life. Creatures that are active only at night will obviously retreat from light of any kind, but others are attracted by habitat produced light. Different colors of light affect sea life in differing ways, and such things as strobe lighting are used to obtain certain reactions for various photographic or scientific procedures.

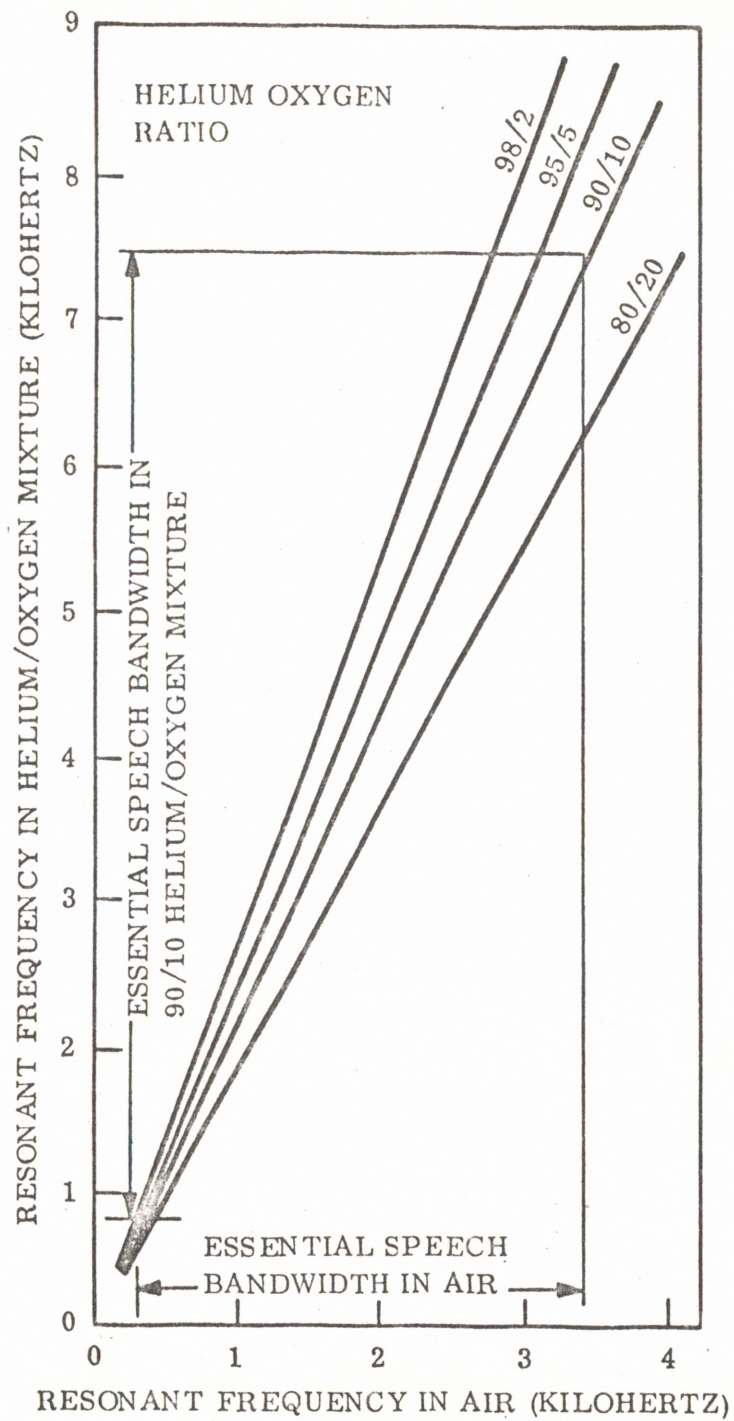
Sense/Sound

Sound becomes a more valuable asset underwater than it is in air --- due mainly to the fact that it travels 4,700 feet/sec. in water as opposed to 1,100 feet/sec. in air and is transmitted better through the denser, more elastic medium.

The picture changes considerably, however, when concerned with sound production within the habitat --- particularly if helium is used as the inert gas in the atmospheric condition. Human speech becomes a soprano gibberish in such an atmosphere, due to the increase in normal speech frequencies caused by the helium. Increased pressure has no effect on speech until depth exceeds 500 feet --- and then it concerns only the lower frequencies.



A diagram of the non-linearity of the ratio --- velocity of sound in Helium-Oxygen mixtures/ velocity of sound in air --- which appears at depths beyond 500 feet.



A diagrammatic comparison of the ratio --- velocity of sound in Helium-Oxygen mixture/ velocity of sound in air --- of various Helium-Oxygen mixtures.

One of the major complaints of past aquanauts concerning the habitats they resided in was the lack of good sound barriers. Mechanical equipment is in some cases very noisy, and can interfere with all activities from sleep to work. There should also be sound separation between work and leisure areas.

Marine life has taken advantage of good sound transmission in sea water. Dolphins and porpoises have evolved their own sound systems, navigating by use of projected and reflected sounds --- they also communicate between each other by the use of sound. Scientists and divers, realizing this fact and another, that these sea-mammals are extremely intelligent, have for some time been working on the training of dolphins and porpoises for helpful assistance to divers, much as horses have assisted men on land for eons. Recent recordings made in the ocean have revealed a din of creature produced sound --- oceanographers are only beginning to sort out who says what and why.

If sound plays as big a part in marine life as it appears, habitat produced sounds must affect the nearby creatures. I have found nothing in my investigation of previous habitats, however, that expresses this as a problem --- whether this is due to the lack of exterior sound produced, or simply the lack of any investigation being performed, I do not know. I have discovered reference to the noise and bubble train of carbon dioxide from scuba equipment as a problem, but that has been eliminated with the advent of closed cycle breathing apparatus for excursion divers.

Sense/Smell

I have been able to obtain very little material on odors produced in sea water, or their transmission. Marine life does possess odor sensing organs and uses them. For example, the bull nosed shark has two widespread nostrils which it uses to locate prey, similar to the way we use our separate eyes to locate objects visually.

The mechanical apparatus which man possesses at this time for breathing underwater constitutes a barrier to odor detection --- I am not certain man could detect odors through water anyway. Of the past habitats I have investigated, no mention of any kind has been made of water borne odors, so I assume it presents no major problems.

Odors produced within an undersea dwelling are a problem, however, particularly due to the atmospheric system being predominantly a closed one. Sources of odors include: cooking, lavatory activities, scientific processes, cleaning processes, natural human processes, and mechanical equipment. Most odors fall into an unpleasant or dangerous category and should be removed, but some are pleasant and thus may possibly be temporarily retained.

I have found nothing stating that the detection of odors by humans is changed in any way by the different atmospheric combinations of oxygen, nitrogen, and helium in underwater habitats; the same seem to hold true for pressure differences.

Sense/Touch

The sensing powers of human skin are often overlooked when preoccupied with understanding eyes, ears and the nose. The human race would have perished long ago if it were not able to sense temperature changes and extremes, which it does by way of the skin receptors. Man is well equipped both to send and receive messages as to his emotional state by means of changes in the skin temperature of various parts of the body. Some people have developed their temperature sensing abilities much more than others --- people who have lost their sight, for example.

Texture can only be fully appreciated through touch --- visual sensing draws little from texture. Texture can express a multitude of messages, from comfort, warmth, and friendliness to harsh, cold rejection. When dealing with underwater habitats, one must constantly remain cognizant of the absorption of water, minerals, and microbiological organisms in various textures.

Water only changes the medium in which touch operates, not the sense itself. Water and wave motions may increase a diver's comprehension of movement.

Atmospheric gases, however, can have marked effects, particularly with respect to temperature. The specific heat and conductivity of helium affect heat transfer mechanisms which tend to chill if the ambient atmospheric temperature is below that of the body. This effect can be circumvented if the gas temperature is maintained nearer 90° F which essentially reduces heat loss from the body. However, heat transfer from the atmosphere of the chamber to the cold walls of the habitat is greatly increased. While on the subject of temperature, it should also be mentioned that the

temperature of the ocean can drop as low as 28° F --- thus requiring extensive heating and insulating mechanisms in the habitat and various auxiliary equipment.

Marine life presents textures from the extremely rough to the extremely smooth --- as well as the extremely dangerous, such as the Portuguese Man-of-war, whose sting can be fatal to man. Many forms of marine life will attach themselves to anything of any texture --- making cleaning problems poignant at times.

Sense/Taste

The sense of taste is utilized the least of any human sense --- it is seldom if ever thought of in terms other than food evaluation and consumption. Taste is closely related to smell, and many times impurifications in air can be "tasted" as well as recognized by their particular odor.

Taste is affected somewhat by the gas helium, used in undersea atmospheres. Many foods lose their individual tastes --- heat is also lost to the atmosphere extremely fast, for example, coffee cools instantly after pouring.

Normalities

Humans consume approximately 20 cubic feet of oxygen per day on land --- this quantity of oxygen is still consumed in a saturated diving situation, but the actual volume is decreased due to the increase in pressure. If aquanauts were to breath a normal air composition for extended periods of time while under increased pressure, their bodies would absorb too much oxygen and narcotic effects would appear. The same holds true for nitrogen, the other major component of air, at greater depths.

The fresh water consumption rate for underwater laboratories is a function of the external water temperature and of the source of supply. For Conshelf III, located in 50°F water and storing its own water, the consumption was restricted to about 20 gallons per man per day. Where water is surface supplied, however, and readily available, consumption can approach 70 gallons per man per day.

The food provided aboard the habitat must be nutritious, providing each crew member approximately 2800 k cal/day of palatable food. Previous aquanauts have consumed one-fourth again as much food as normal while on missions, and have stressed the importance of an interesting and varied menu. This translates into approximately .03 ft³/man of frozen foods, .05³ft /man of chilled foods, and .1³ft /man of dry foods per day.

The temperature and humidity of underwater habitats must be adequately controlled to provide the occupants with a comfortable working/living atmosphere. The temperature should range somewhere between 70°F and 80°F in air or high nitrogen atmosphere. In helium atmospheres, it should remain around 90°F, due to the different specific heat and conductivity of helium. Relative humidity was maintained between 42% and 60% in Tektite, a high nitrogen habitat. In

helium atmospheres, 40% to 80% relative humidity with minimal atmospheric movement has been recommended. Excursions from the habitat also produce body heat deficiencies, even in tropical waters, and returning aquanauts need to be returned to and maintained at comfort levels as quickly and efficiently as possible - this has previously been done principally through the use of a hot shower.

I have encountered one reference to the absence of sunlight --- aquanauts of Jacques - Yves Cousteau's Conshelf II were required to expose themselves to six minutes of artificially produced ultra-violet rays each day.

Many and varied studies have been made of the constant immersion of aquanauts, and their interaction with the multitude of microbiological organisms in sea water. The only major problem to have surfaced has been that of ear infections --- due mainly to the incomplete removal of sea water from the auditory canals after returning from an excursion. This problem has been pharmaceutically solved, however. Normal cleanliness has shown to be sufficient protection against any other types of contaminant infection. Small cuts and scratches have been found to heal faster in a pressurized atmosphere.

I have uncovered no reference to human diver contamination of marine life --- I would suspect it is taken for granted that an infected individual would not be allowed in either the water or the habitat, and thus would not threaten infection of marine life.

Even though scientists working from undersea habitats undertake a lot of physical activity by the very nature of their work, exercising equipment and the room to use it have been requested in the design of future facilities.

Human wastes produced in undersea habitats differ in no significant way from those produced on the surface. Their removal is still a required measure for health and safety. It is obvious that the expulsion of wastes into the surrounding sea will have some effect upon the life of the water, affecting it to a degree reflecting the potency and quantity of the waste expelled. Odor problems may become somewhat more serious due to the closed atmospheric system of the habitat.

Limitations

Tests for space flights have shown men can survive on between three quarters and one gallon of water per day. This figure includes drinking water, personal hygiene, and requirements for food rehydration.

The minimum amount of food required to sustain human life is a very dependent factor --- on individual stamina, individual metabolism, and stored nutrients in the body, to name a few. The minimum nutriment required is also determined by how long a person must survive under such conditions, and how much work he must perform.

The breathing gas contaminant concentration that can be tolerated by the human body is directly related to the time of exposure to the contaminant. Many contaminants found in submarines, habitats, and space vehicles have been identified and their concentrations determined.

Compound	Chemical Formula	Suspected Source	Limit 1 Hour	Limit For 90 Days
Acrolein	CH_2CHCHO	Cooking		-
Arsine	AsH_3	Battery Gassing		0.01 PPM
Ammonia	NH_3	Scrubbers (Metabolic)	400 PPM	25 PPM
Carbon Dioxide	CO_2	Breathing	5%	1%
Carbon Monoxide	CO	*Smoking (Metabolic)	200 PPM	26 PPM
Chlorine	Cl_2	Chlorate candles		0.5 PPM
Ethylene	C_2H_4	Polyethylene Decomposition		-
Formaldehyde	CH_2O	Cooking combustion		-
Freon 12	CCl_2F_2	Air Conditioning		500 PPM
Hydrocarbons (other than CH_4)		Paints		-
Hydrogen	H_2	Battery Gassing		3%
Hydrogen Chloride	HCl	Freon decomposition	50 PPM	0.1 PPM
Hydrogen Fluoride	HF	Freon decomposition	5 PPM	0.1 PPM
Mercury	Hg	Equipment/ Thermometers	-	0.05 Mg/M^3
Methane	CH_4	Sanitary Tanks	-	5.3%
Methylalcohol	CH_3OH	-	-	3 PPM
Monoethanolamine	$\text{HOCH}_2\text{CH}_2\text{NH}_2$	CO_2 Scrubbers	100 PPM	1 PPM
Nitrogen Dioxide	NO_2	Burners (Contaminant or hot surfaces)	10 PPM	0.05 PPM
Nitric Oxide	NO	Burners (Contaminant or hot surfaces)	10 PPM	0.05 PPM
Ozone	O_3	Precipitators	1 PPM	0.05 PPM
Phosgene	CoCl_2	Freon decomposition	1 PPM	0.05 PPM
Stibine	SbH_3	Battery Gassing	1 PPM	0.05 PPM
Sulfur Dioxide	SO_2	Oxidation Sanitary Tank Gases		-

* Smoking should be prohibited.

CONTAMINANTS AND LIMITS

In addition to carbon dioxide, there are numerous contaminants produced by the human body from the mouth, body surface and digestive tract. The production rate is a function of the food being consumed, and the activity and bathing of the occupants.

SOURCE AND FORM OF CONTAMINANTS

SOURCES	PROCESSES	PRINCIPAL CONTAMINANTS
<u>A. Biological</u>		
Man:		
Respiration	Exhalation, sneezing, coughing, evaporation	CO ₂ , CO, mucus, bacteria, virus
Flatus	Flatulation	H ₂ , H ₂ S, CH ₄
Urine	Micturition, spillage, storage, evaporation	Many acids, urea, ammonia, phenols, inorganic salts
Sweat	Perspiration, evaporation	Ammonia, phenol, acids, inorganic salts
Sebum	Secretion, vaporization	Fats, fatty acids, odoriferous substances and acids, desquamated epithelium
Feces	Defecation, spillage, storage, evaporation	Ammonia, phenols, indole, skatole, methyl mercaptan, paracresol, bacteria
Hair, nails	Depilation, clipping, shaving	Particulate debris
Cerumen	Secretion, vaporization	Odoriferous waxes
Microbes	Indigenous body organisms	Bacterial debris, possible infectious organisms
<u>B. Nonbiological</u>		
Food, beverages	Spillage, decomposition, regurgitation	Debris, odors, provide substrates for microbial proliferation
Waste disposal systems	Spillage, leakage, decomposition	Debris, odor, noxious gases, microbial proliferation
Construction materials		
Metals	Wear, oxidation, galvanic corrosion	Dust, metallic oxides, H ₂
Plastics	Wear, heat	Dust, phenol, formaldehyde, other noxious vapors
Other nonmetals	Wear, decomposition	Dust, substrates for autotrophic growths
Paints	Wear, vaporization	Dust, toxic organic vapors
Lubricants	Spillage	Aerosol formation, odors
Electronic gear, insulation	Corona discharge, ionization, heat	Ozone, ionized air, phenol, formaldehyde
Electrical motors, batteries	Wear, power generation and conversion	Ozone, ionized air, H ₂

In general, all items placed in the habitat should be carefully selected to eliminate the production and/or release of contamination due to curing, aging, wear, reaction, spillage, deterioration, etc.

Humans can stand temperature extremes according to how long they must endure how extreme a temperature.

Studies of stress perturbations and their consequences were made during Tektite II, but I was unable to obtain the results. During that series of missions there were several earthquakes and one potential hurricane that resulted in an aborted mission.

No limits of the depth at which humans can dive or work have been established to this date. Using Helium, chamber saturation dives have been made to 2,000 feet and open ocean commercial working dives to 840 feet.

Dimensions

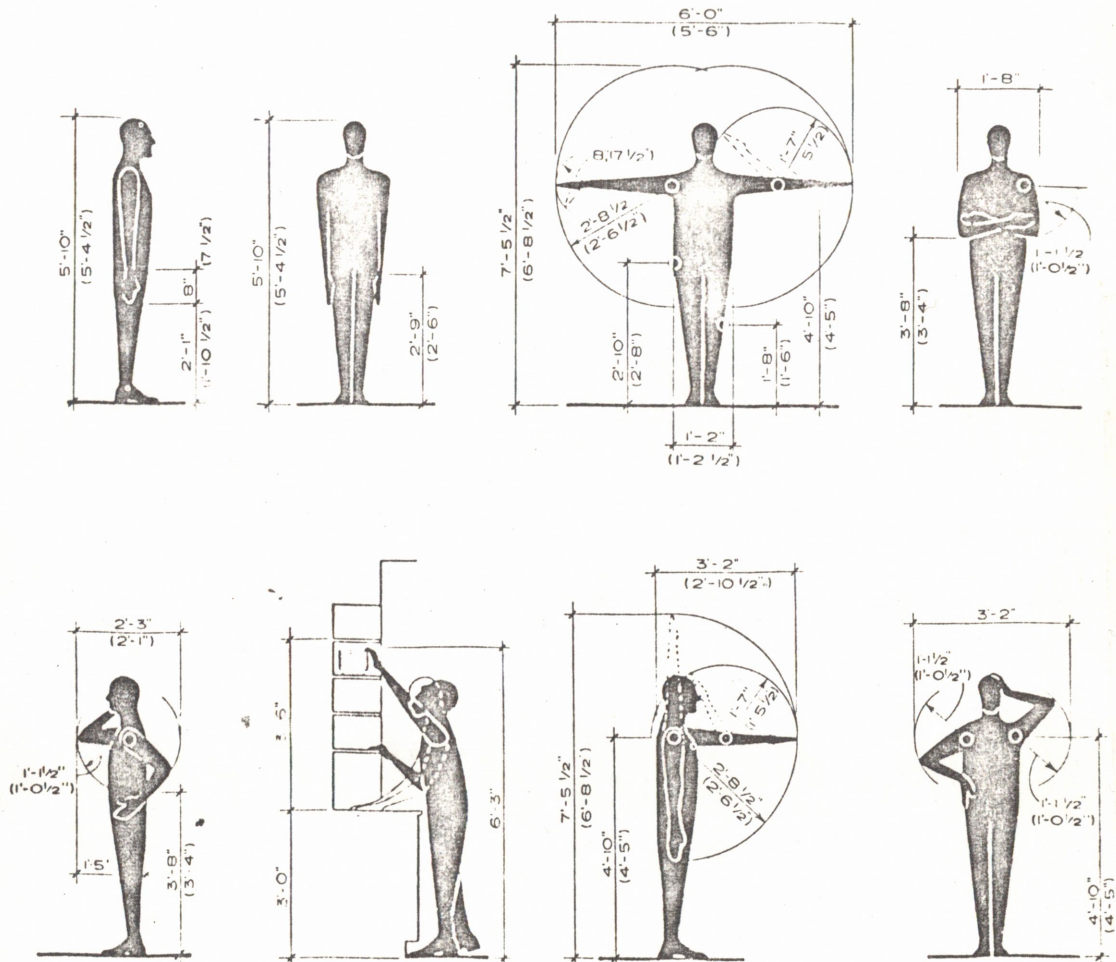
The average human size and its dimensional clearances in various positions are shown in the following diagrams.

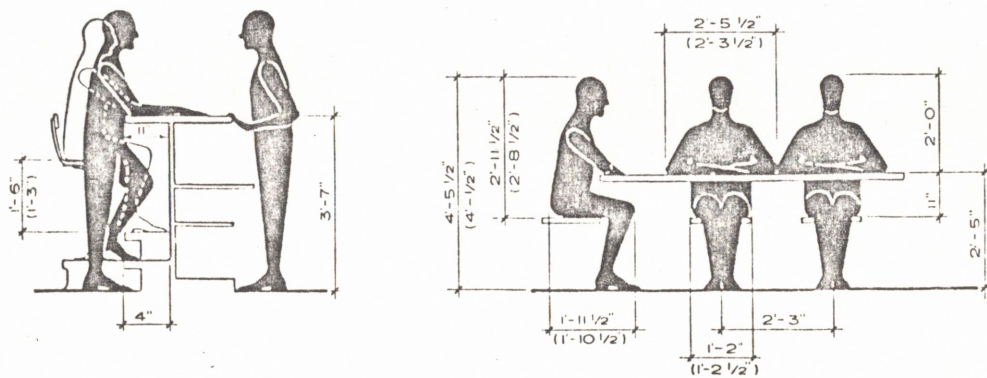
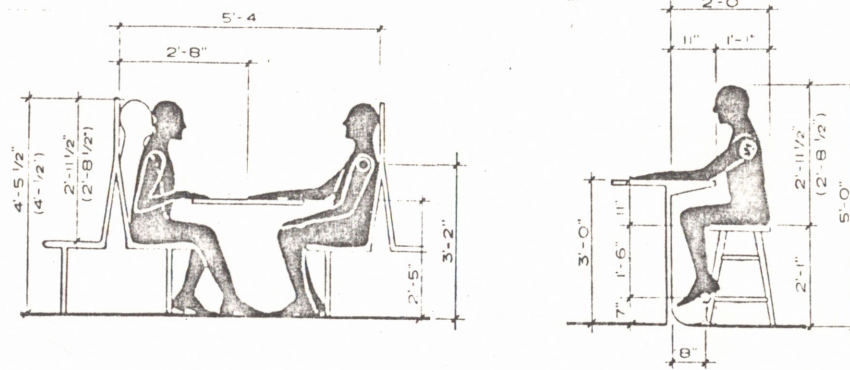
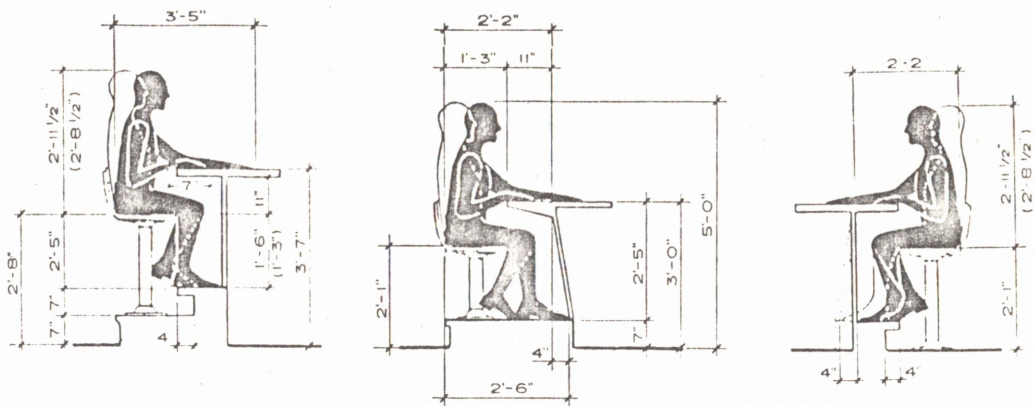
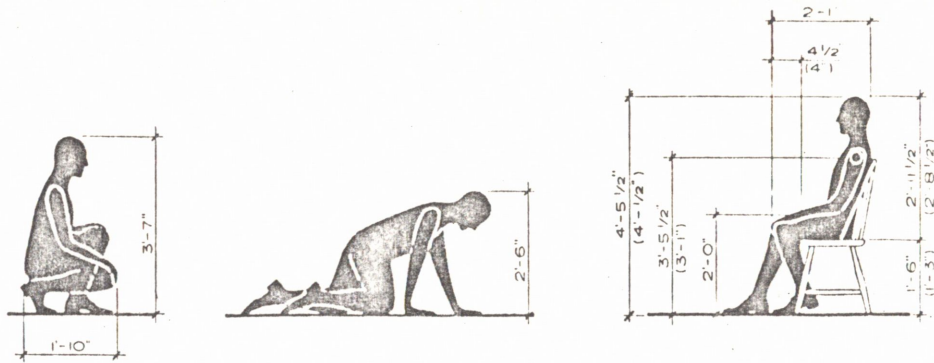
KEY TO DIMENSIONS

2'-3" MEN
(2'-1") WOMEN

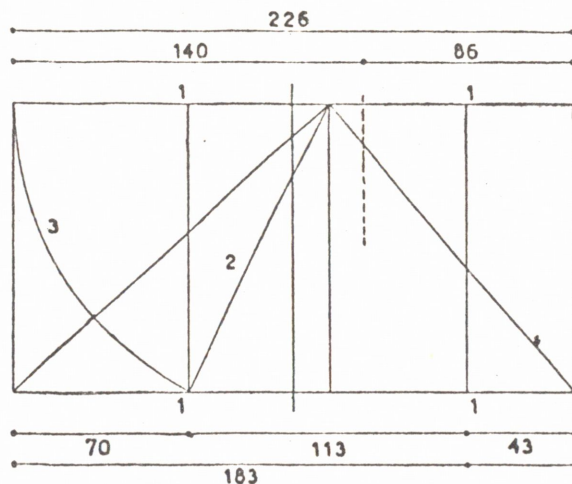
GENERAL NOTES

1. Dimensions shown are based on the average or normal adult.
2. Clearances are generally minimum and should be increased when conditions allow.
3. Seating heights and table top heights shown on this page may be varied slightly; refer to furniture pages.





Perhaps the best known and most easily used definition of human proportions is Le Corbusier's Modulor, based on the Fibonacci series.



1. The Grid furnishes three measures: 113, 70, 43 (in centimetres), in a relationship Φ (golden section); the Fibonacci series furnishes $43 + 70 = 113$, or $113 - 70 = 43$. Added together they give $113 + 70 = 183$, $113 + 70 + 43 = 226$.

2. These three measures (113—183—226) define the occupation of space by a man six feet in height.

3. The measure 113 furnishes the golden mean 70,¹ which starts off a new series called the *red series*: 4-6-10-16-27-43-70-113-183-296, etc. . . .

The measure 226 (2×113) (the double unit) furnishes the golden mean 140-86, which starts off the second series, called the *blue series*: 13-20-33-53-86-140-226-366-592 . . .

4. Some of these values of measures can be described as being characteristically related to the human stature.

(1) The registered trade mark used by us up to the present may benefit from an improvement of the drawing. So far, the man-standing-upright confirms three, rather than four, essential values of the 'Modulor', namely:

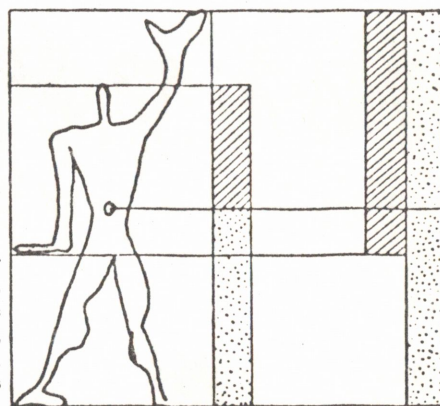
- 113 the solar plexus,
- 182 the top of the head (relationship Φ of 113),
- 226 the tip of the fingers of the upraised arm.

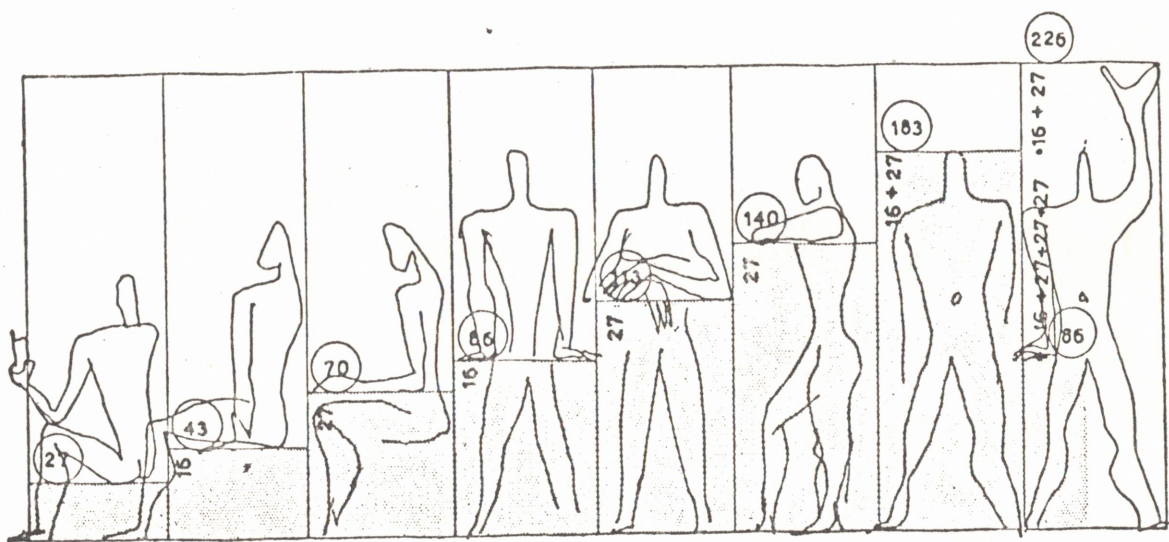
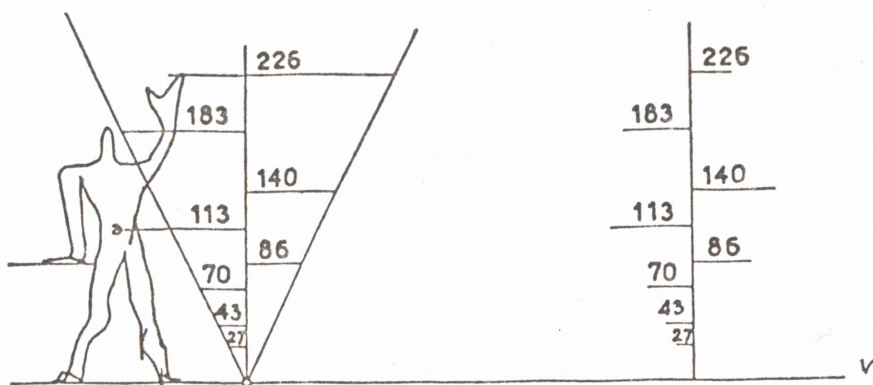
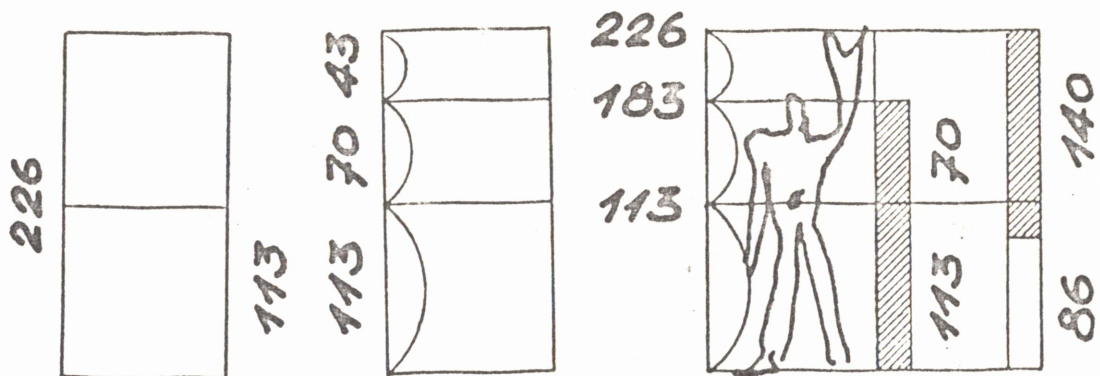
The second relationship Φ (140-86) introduces a fourth essential point of the human figure, namely the place where the hand rests (86 cm.).

Consequently, the man with left arm upraised and right hand concealed will disengage that hand and rest it on a point 86 cm. above the base. In this way the four determining points of the occupation of space by the human figure will be fixed.

And here, twenty years after Matila Ghyka first wrote of it (1927) (The Aesthetics of Proportions in Nature and the Arts), is the manifestation of the TRIAD—solar plexus, head, tip of fingers and upraised arm—and of the DUALITY: solar plexus and tip of fingers, a twofold reality and a limitless one, the triad in the red series, the duality in the blue series of the 'Modulor'.

'The bodies of animals and insects also disclose in many of their proportions the theme of the golden section; in the forelegs of the horse, as much as in the index of the human hand, appears the series of three consecutive terms of a diminishing series Φ ; this triad is very important, for, because its highest term is equal to the sum of the other two terms, it re-introduces duality, the symmetrical division which it contradicts *a priori*. That will be its value to architecture'.





Psychological Attributes

The following list of psychological needs is taken from a paper by Peggy Peterson, University of California at Berkeley, entitled The ID and the Image: Human Needs and Design Implications.

Need/Harm Avoidance

Safety Needs. Avoid pain.

Description: This need is really a self-protecting device; it implies avoiding pain, physical injury, illness, and death, escaping a dangerous situation, and taking precautionary measures. Individuals also take great measures to avoid psychological pain. Freud believed that all human behavior was determined by the principle of avoiding pain and seeking pleasure.

Need/Sex

Description: To form and further an erotic relationship - to have sexual intercourse. Henry Murray is by no means the only person to label sex a need; it is universally recognized as such. Some individuals even feel that it should be classified as a physical need along with food and water.

Need/Affiliation

Belongingness, Brotherliness and Relatedness, Cooperation and Social Instinct, Affection and Approval.

Description: This category includes the need for being with others - a desire to please and win affection, to remain loyal to a friend, to enjoyably cooperate or reciprocate with another who resembles or likes the subject. Affiliation has been related to many things, even anxiety seems to diminish as affiliation increases.

X

Need/Nurturance

Need to be needed. Humanitarianism and Altruism.

Description: These terms encompass the needs to give sympathy and gratify the needs of a helpless object, to assist an object in danger, to feed, help, support, console, protect, comfort, nurse and heal. In short, the need to feel that one is needed and wanted by another human being or by society.

Need/Succorance Protection

Description: This is the opposite of nurturance. It is the need to have one's needs gratified by the sympathetic aid of an allied object, to be nursed, supported, sustained, surrounded, protected, loved, advised, guided, indulged, forgiven, consoled, to remain close to a devoted protector, to always have a supporter.

Need/Security

Description: This is a desire to be free from fear, anxiety, care, risk, or danger.

Need/Order

Description: A need to put things in order, to achieve cleanliness, arrangement, organization, balance, neatness, tidiness or precision.

Need/Frame of Orientation Philosophy of Life-Rootedness

Description: This category includes many related ideas. Man needs a consistent and stable way of perceiving and comprehending the world; he needs to feel he belongs to the world and is a part of it. The mature man needs a philosophy of life as a unifying force and orientation.

X

A RESTAURANT AND RECREATIONAL PARK

in

BUTTE, MONTANA

by

Paul W. Powers

A thesis submitted in partial fulfillment
of the requirements for the degree
of

BACHELOR OF ARCHITECTURE

Peter Kommers
Thesis Advisor

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Montana State University

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Need/Dominance

Superiority, Power

Description: These terms indicated a need to control one's human environment; to influence or direct the behavior of others by suggestion, seduction, persuasion or command; to dissuade, restrain or prohibit. A desire to be superior, to dominate.

Need/Infaviodance

Avoid Inferiority

Description: This is a rather passive solution to the problem of humiliation. It is a need to avoid humiliation; to quit embarrassing situations or to avoid conditions which may lend to belittlement: The scorn, derision, or indifference of others; to refrain from action because of the fear of failure.

Need/Defendance

Description: Here we have a more active defense of the self against assault, criticism, and blame; a need to conceal or justify a misdeed, failure, or humiliation; to vindicate the ego.

Need/Counteraction

Description: This is an active striving to obliterate a humiliation by resumed action; to master or make up for a failure by restriving. It includes a need to overcome weakness, to repress fear; to efface a dishonor by action; to search for obstacles and difficulties to overcome; to maintain self respect and pride on a high level.

X

Need/Achievement

Sense of accomplishment, Perfection, Effectance.

Description: This is a need to accomplish something difficult; to master, manipulate, or organize physical objects, human beings or ideas, and to do this as rapidly and as independently as possible, to overcome obstacles and attain a high standard; to excel oneself; to rival and surpass others; to increase self regard by the successful exercise of talent. John Atkinson and David McClelland, who have intensively studied achievement, include three categories: unique accomplishment, long-term involvement, and competition with a standard of excellence.

Need/Prestige

Esteem, Personal Admiration.

Description: This is the positive side of the humiliation coin. People need to have the respect of others and themselves: recognition.

Need/Aggression

Description: This is a need that people often deny and repress. It is the need to overcome opposition forcefully; to fight, to revenge an injury, to attack, injure or kill another, to oppose forcefully or punish another.

Need/Rejection

Description: This is a need to separate oneself from a disliked object, to exclude, abandon, expel, or remain indifferent to an inferior object, to snub or jilt an object. In short, it is the need to be able to show disapproval.

Need/Deference

Description: People have a need to admire and support a superior, to give praise, to honor, to eulogize, to yield to the influence of an allied other, to emulate an exemplar, and to conform to custom. This is a complement of autonomy and aids the prestige of others.

Need/Abasement

Self submission, self surrender.

Description: These terms encompass the need to submit passively to external force; to accept injury, blame, criticism, punishment, to surrender; to become resigned to fate, to admit inferiority, error, wrongdoing, or defeat; to confess and atone; to blame, belittle, or mutilate the self; to seek and enjoy pain, punishment, illness and misfortune.

Need/Play

Leisure

Description: This is a complex need that is just beginning to be understood. It is a need to act for "fun" without further purpose; to like to laugh and make jokes; to seek enjoyable relaxation of stress; to participate in games, sports, dancing, drinking parties, cards, etc..

Need/Variety

Sentience

Description: People need change in their life and their environment. D. O. Hebb's experiments at McGill University show that variety is not only the spice of life, but its sustaining force; within a very short time subjects went literally "out of their minds" when they were deprived of all sensory stimulation. People need to seek and enjoy sensuous impressions.

Need/Understanding
Cognitive needs

Description: This need can be thought of as a thirst for knowledge - a need to ask or answer general questions; to speculate, formulate, analyze, and generalize.

Need/ Meaningfulness in Life
Goal

Description: To give life meaning man needs a sense of purpose or a goal. Man needs a reason to be (*raison d'etre*). When this is entirely lacking, man is close to suicide.

Need/Self Actualization, Self Realization
Transcendence

Description: These terms refer to man's need to realize his full potential as a human being - to rise above his animal nature and become a creative person.

Need/Aesthetic

Description: According to Maslow this is the highest of all human needs - the desire for beauty.

One psychological problem encountered in situations such as undersea habitats but not mentioned previously is that of isolation and very restricted movement. Claustrophobia can be lessened to a certain extent by attempting to make the habitat seem as spacious as possible, but this can only go so far. Communication links with others in the sea can also help alleviate some of the stresses of isolation. But in the end it is going to have to be a process of screening out the individuals who are susceptible to isolation and claustrophobia, and not allowing them to undertake underwater missions.

X

Sociological Attributes

Individuals

Of utmost importance in discussing the individual's social needs is the capability of the individual to isolate himself from the rest of the occupants of the habitat, without entering the water. (An individual diving alone is frowned upon for safety reasons.) Some means must be provided for the individual to withdraw from the rest of the aquanauts --- to be alone with his own thoughts. This isolation entails more than mere spatial separation --- it must also consider audio and visual separation. Such activities as sleeping and self-maintenance also require a degree of privacy which must be provided within the habitat.

There is also a need for the individual to identify himself with the group. This need can be met by providing space and means for "doing your own thing", and by providing a territory which belongs solely to the individual occupying it, and is recognized as such by the rest of the habitat occupants.

Although the isolation and close working quarters of the facility may tend to foster individual interaction with group activities, attention should be paid to extending an invitation of sorts to the individual to do so. This must not conflict, but must rather balance with the provisions for individual isolation within the facility.

Pairs

The formation of pairs falls into a sort of limbo between group and individuals --- while not requiring the quantity of space or facilities of groups, they do require the isolation or individuality of a single person alone. I may be assuming too much but it appears to me that pairs are usually formed for purposes of a more quiet nature than groups --- conversation, working on a project, or scientific endeavor of some kind. When a pair is formed for a loud, boisterous activity, it draws the interest and attention of others nearby, and may very likely evolve into a group activity.

Excursions into the water are almost always done in pairs for safety sake, and as a result many scientific inquiries are undertaken as a joint project by two individuals. This cooperative work goes far in strengthening the pair bond, and as a result the working pair assumes needs similar to those of a working individual --- quiet, concentration, and lack of interruption.

Facilities for the working pair need flexibility to adapt to changing pairs from mission to mission, but the use of the same facilities by differing pairs during a single mission is considerably less than that of groups. True, there are many pieces of lab equipment used by all, but each project has its own peculiar apparatus, chemicals and storage requirements, and may require an assemblage of tools which would be impractical to dismantle constantly to allow others to use the same space. Extreme care also must always be taken to avoid cross-contamination of specimens under study, and confusing mixups of data and observations. It would appear then that working pairs demand a sizable area of separable work space, with care not to overlap distinct work areas.

X

The leisure pair seems to fit quite successfully into either the group activities area or the individual area, without requiring a separate section of the habitat.

Need/Solitude
Privacy

Description: This is the complement of the need for affiliation; people need to have some time alone.

Need/Autonomy
Self-determinism, Self-sufficiency and
Independence.

Description: This is a need to get free, shake off a restraint, break out of confinement; to resist coercion and restriction; to avoid or quit activities prescribed by domineering authorities; to be independent and free to act according to impulse; to be unattached, irresponsible; to defy convention; to determine one's own behavior.

Need/Identity
Uniqueness

Description: Each individual needs to know who he is and recognize himself as a human being distinct from others and his surroundings. He needs to be unique. Identity formation is a continuous process; however, adolescence is a particularly important stage in its formation.

Need/Exhibition
Self assertion

Description: A need to make an impression; to be seen and heard; to excite, amaze, fascinate, entertain, shock, intrigue, amuse, or entice others. To assert one's self.

4

as a detriment to concentration --- probably an asset to a rowdy poker game, but a detriment to a work activity requiring concentration and no interruption.

The list of activities and their ramifications could go on forever --- the number of reasons the human mind can engender for group interaction is not finite --- and thus I believe my case for flexibility may be laid to rest. The flexibility itself does have some facility requirements however --- ample storage space; careful consideration of traffic patterns; maximum versatility in lighting, electrical outlets, etc; the possibilities of retractable partitions --- basically all fitting under the concept of maximum user manipulation.

Concurrent with this flexibility is the need for group identification, and for identification with a group. Much of this identification may be taken care of through established patterns of space usage at particular times, but physical evidence of specific groups should still be available. This implies fixed elements within the myriad of changing elements --- perhaps posters on the walls, or specific colors for maneuverable elements belonging to a specific group activity.

8

operations

Connections

Before illustrating connections, the facilities must be categorized as to what is to be connected. For the purposes of this paper I have chosen the following area divisions:

- sleep/individual
- lavatory
- group activity
- work
- control
- food preparation
- work storage
- life support storage
- entry/exit
- mechanical
- emergency/decompression
- auxiliary vehicle

Perhaps the easiest way to present these connections is in diagramatic form --- a connection diagram for spatial, visual, auditory, and olfactory.

- + desirable
- o neutral
- undesirable

Spatial

SLEEP/INDIVIDUAL														
GROUP ACTIVITY	0													
WORK AREA	-	0												
CONTROL CENTER	0	+	+											
LAVATORY	+	+	+	0										
FOOD PREPARATION	0	+	-	0	-									
LIFE SUPPORT STORAGE	0	+	0	+	0	+								
WORK STORAGE	-	0	+	0	-	-	+							
MECHANICAL	-	0	0	+	0	0	0	0						
EMERGENCY/DECOMPRESSION	+	+	+	+	0	+	+	0	-					
ENTRY/EXIT	0	0	+	+	+	0	+	+	+	+				
EXTERIOR	0	0	+	+	0	-	+	+	+	+	+			
AUXILIARY VEHICLE	-	0	+	+	-	0	+	+	+	+	+	+		
	SLEEP/INDIVIDUAL	GROUP ACTIVITY	WORK AREA	CONTROL CENTER	LAVATORY	FOOD PREPARATION	LIFE SUPPORT STORAGE	WORK STORAGE	MECHANICAL	EMERGENCY/DECOMPRESSION	ENTRY/EXIT	EXTERIOR	AUXILIARY VEHICLE	

Visual.

SLEEP/INDIVIDUAL													
GROUP ACTIVITY	-												
WORK AREA	-	O											
CONTROL CENTER	O	+	+										
LAVATORY	-	+	+	O									
FOOD PREPARATION	-	+	O	O	-								
LIFE SUPPORT STORAGE	-	+	O	O	O	+							
WORK STORAGE	-	O	+	O	O	O	O						
MECHANICAL	-	O	O	+	O	O	O	O					
EMERGENCY/DECOMPRESSION	+	+	+	+	O	O	+	O	+				
ENTRY/EXIT	O	+	+	+	+	-	+	-	+	+			
EXTERIOR	+	+	+	+	-	O	+	+	+	+	+		
AUXILIARY VEHICLE	O	O	+	+	O	O	+	+	+	+	+	+	
	SLEEP/INDIVIDUAL	GROUP ACTIVITY	WORK AREA	CONTROL CENTER	LAVATORY	FOOD PREPARATION	LIFE SUPPORT STORAGE	WORK STORAGE	MECHANICAL	EMERGENCY/DECOMPRESSION	ENTRY/EXIT	EXTERIOR	AUXILIARY VEHICLE

Auditory

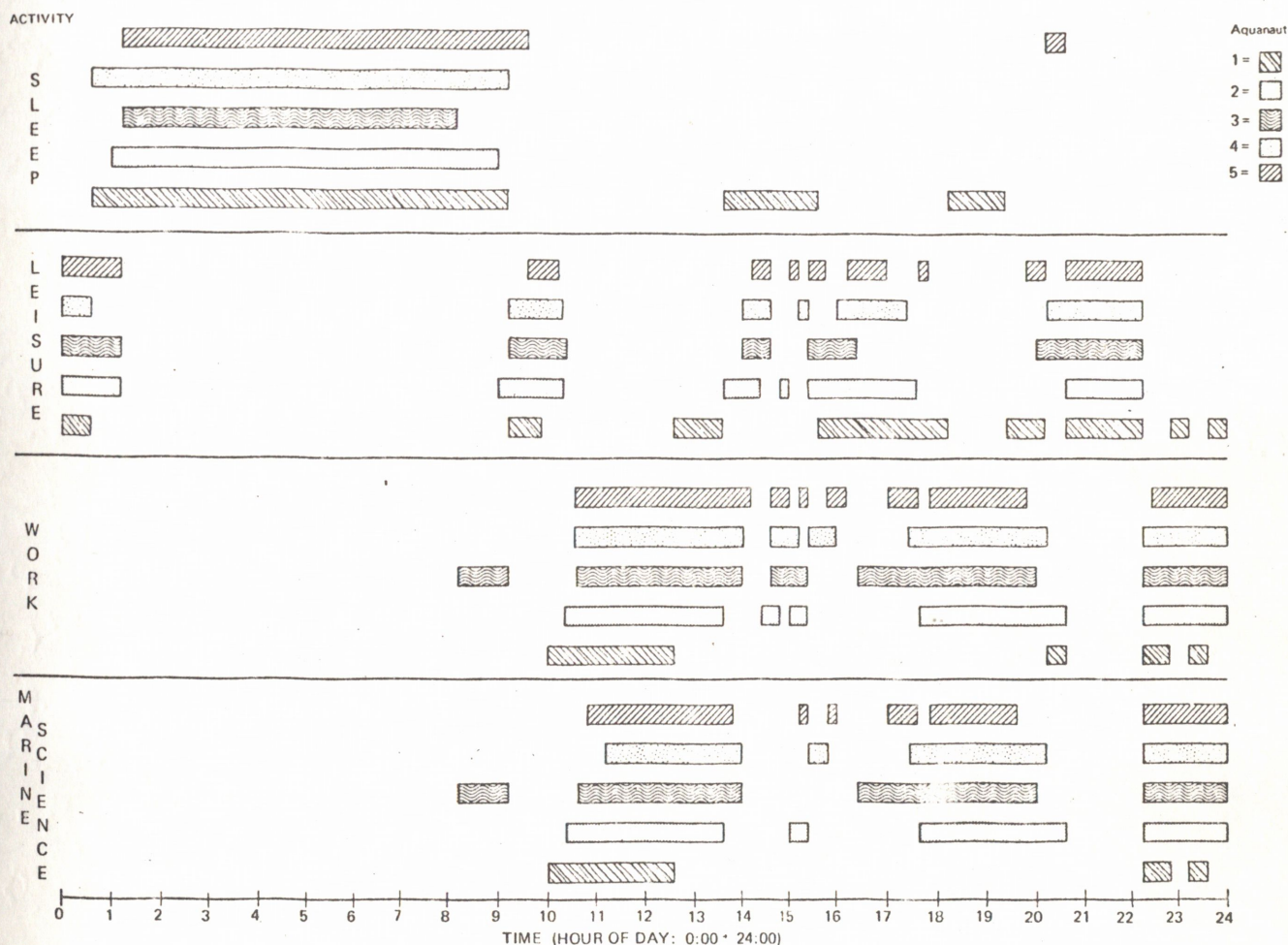
SLEEP/INDIVIDUAL														
GROUP ACTIVITY	-													
WORK AREA	-	-												
CONTROL CENTER	+	+	+											
LAVATORY	-	-	-	+										
FOOD PREPARATION	-	+	-	+	-									
LIFE SUPPORT STORAGE	-	+	o	+	o	+								
WORK STORAGE	-	o	+	+	-	o	+							
MECHANICAL	-	-	-	+	o	o	o	o						
EMERGENCY/DECOMPRESSION	+	-	+	+	o	+	+	o	+					
ENTRY/EXIT	-	o	+	+	o	o	+	+	+	+				
EXTERIOR	o	+	+	+	-	o	+	+	+	+	+			
AUXILIARY VEHICLE	-	+	+	+	-	o	+	+	+	+	+	+		
	SLEEP/INDIVIDUAL	GROUP ACTIVITY	WORK AREA	CONTROL CENTER	LAVATORY	FOOD PREPARATION	LIFE SUPPORT STORAGE	WORK STORAGE	MECHANICAL	EMERGENCY/DECOMPRESSION	ENTRY/EXIT	EXTERIOR	AUXILIARY VEHICLE	

Olfactory

SLEEP/INDIVIDUAL														
GROUP ACTIVITY	O													
WORK AREA	-	-												
CONTROL CENTER	O	O	O											
LAVATORY	-	-	-	O										
FOOD PREPARATION	-	+	O	+	-									
LIFE SUPPORT STORAGE	-	O	-	+	O	O								
WORK STORAGE	-	-	O	+	-	-	O							
MECHANICAL	-	-	-	+	O	-	O	O						
EMERGENCY/DECOMPRESSION	O	O	O	+	O	O	O	O	O					
ENTRY/EXIT	-	O	O	O	-	O	O	O	O	+				
EXTERIOR	-	O	O	O	-	O	O	O	O	+	+			
AUXILIARY VEHICLE	-	-	O	+	-	-	O	O	O	+	+	O		
	SLEEP/INDIVIDUAL	GROUP ACTIVITY	WORK AREA	CONTROL CENTER	LAVATORY	FOOD PREPARATION	LIFE SUPPORT STORAGE	WORK STORAGE	MECHANICAL	EMERGENCY/DECOMPRESSION	ENTRY/EXIT	EXTERIOR	AUXILIARY VEHICLE	

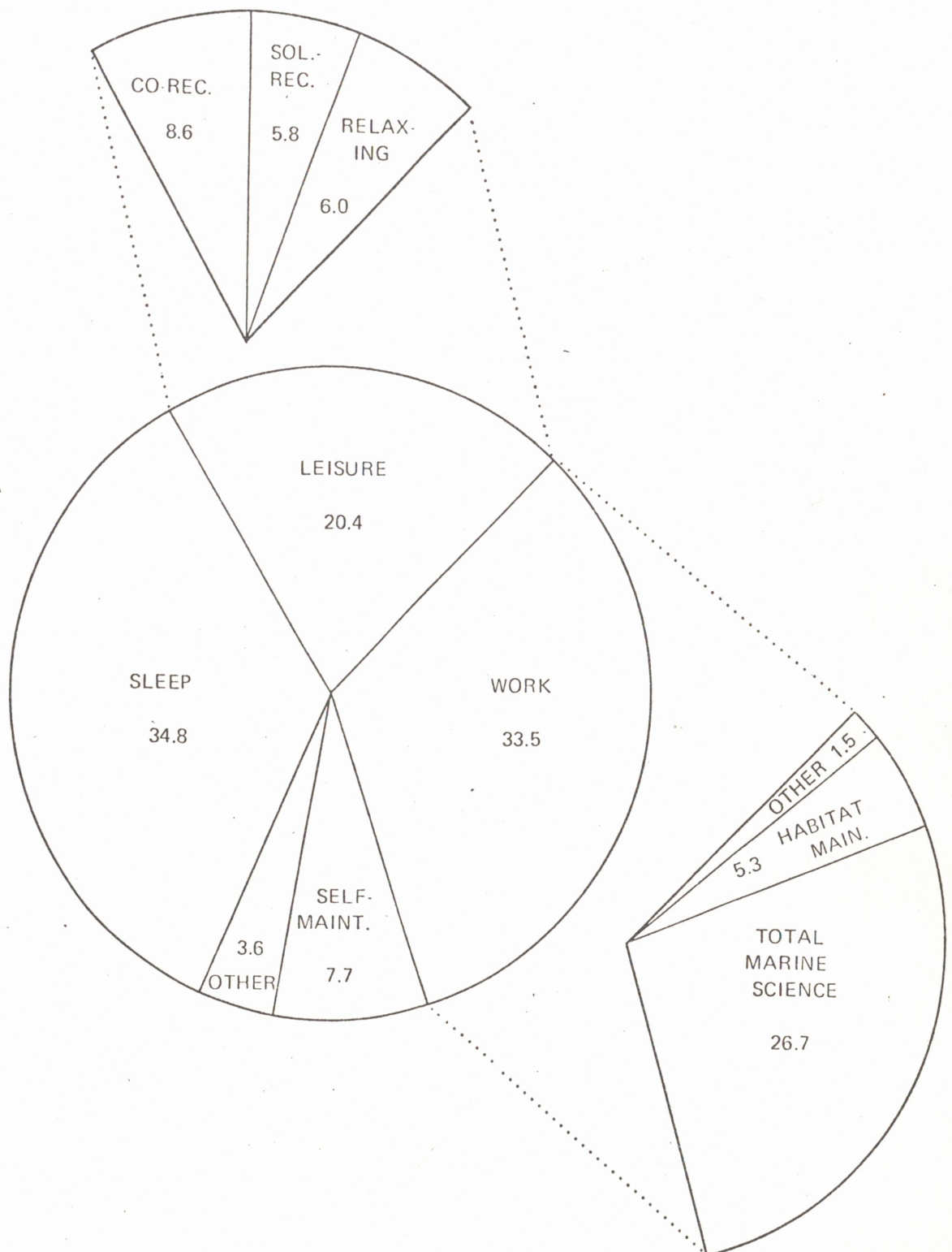
Sequences

The sequential activities of a habitat scientist varies in no significant way from that common in surface laboratories. Things which do affect the sequence of activities --- the fact that aquanaut scientists literally live at their lab; the lack of prescribed schedules dependent on public facilities (no buses to catch); the remoteness of major administrative activities and other interruptions; the limited scope of social and leisure activities.



Graph depicting the daily sequence of each aquanaut's activities during Tektite I.

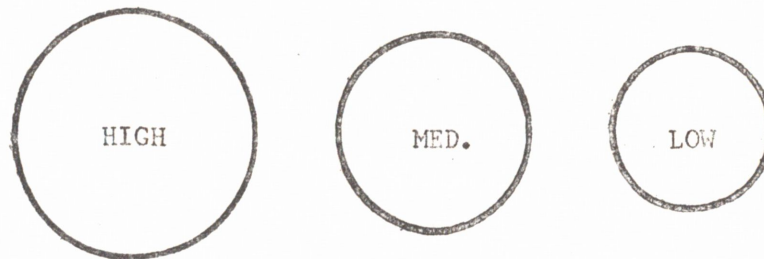
The following diagram, adopted from studies during Tektite II, shows the mean percentage of total mission time spent on various activities.



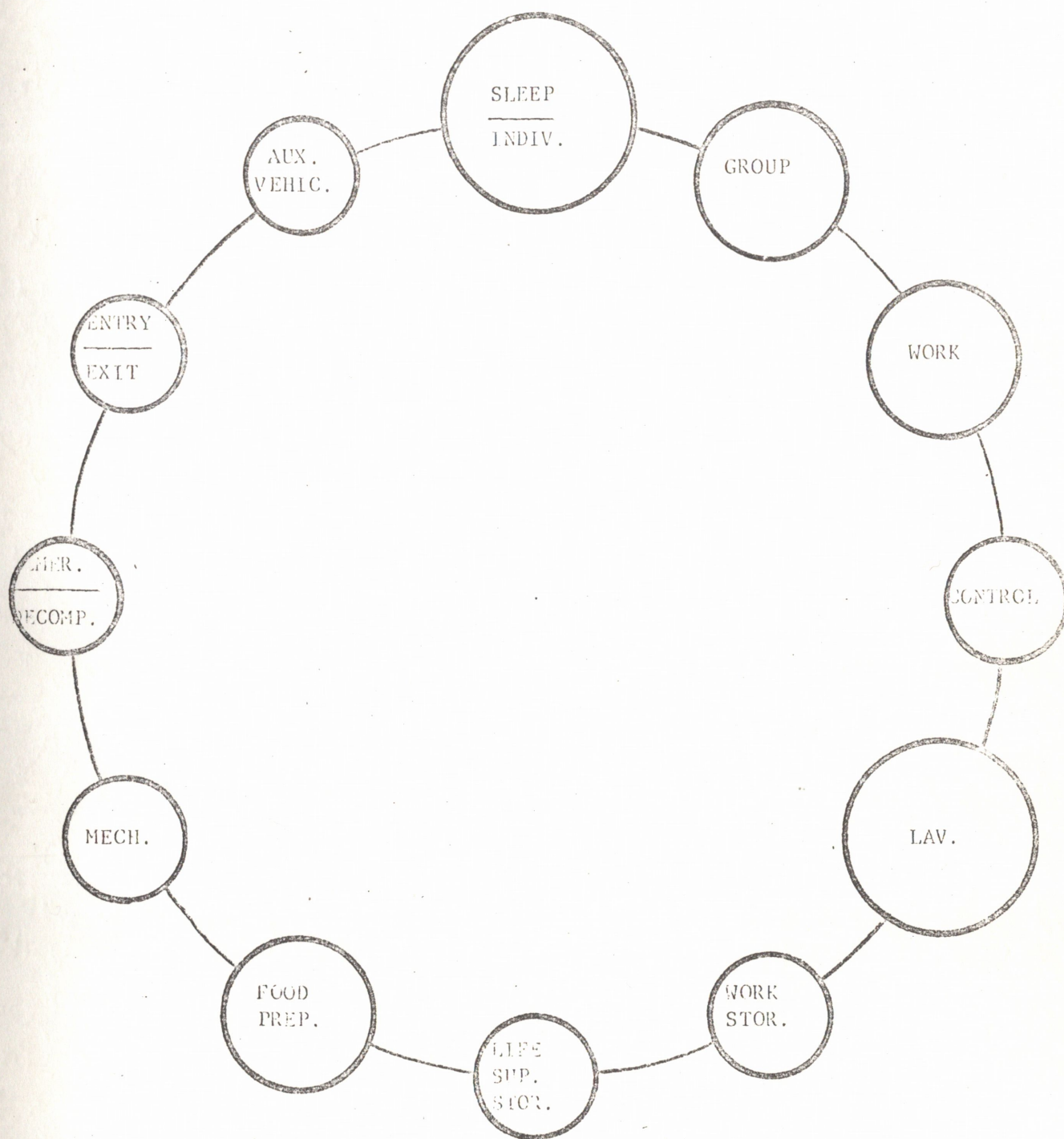
Patterns

The combination of data on connections and sequences, plus various other inputs, provides graphic patterns indicating major design considerations.

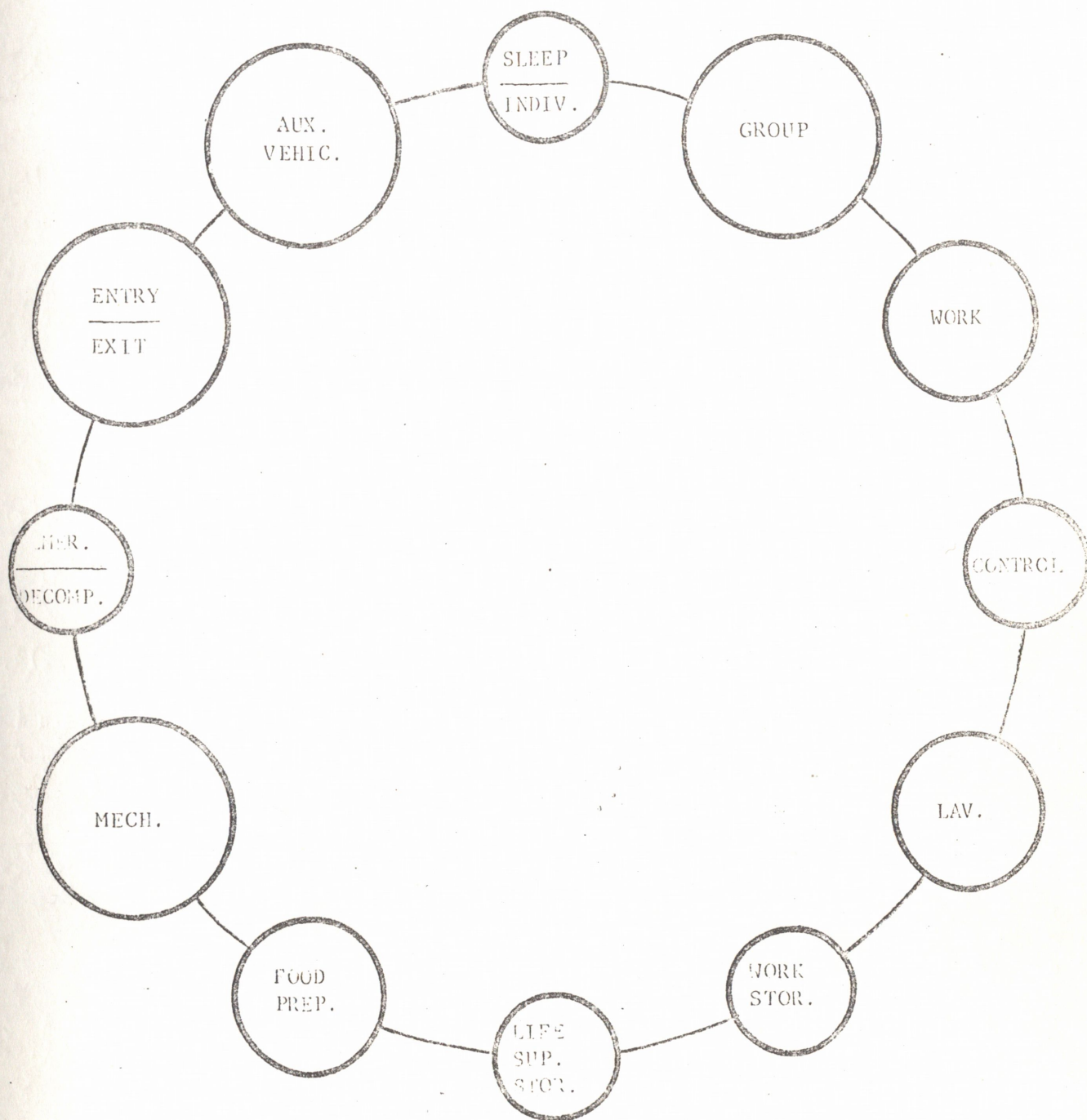
Representations of degree:



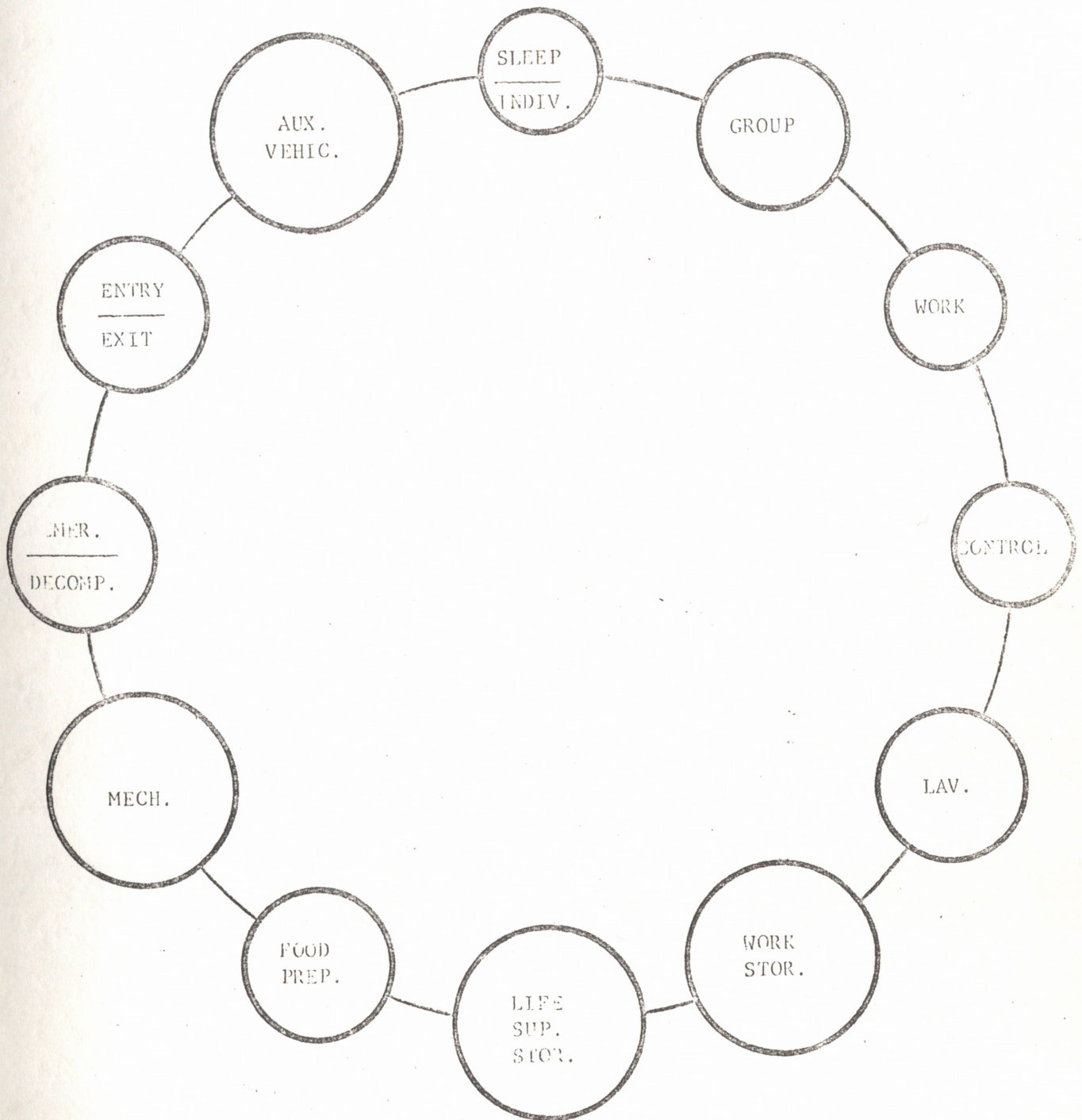
Visual isolation



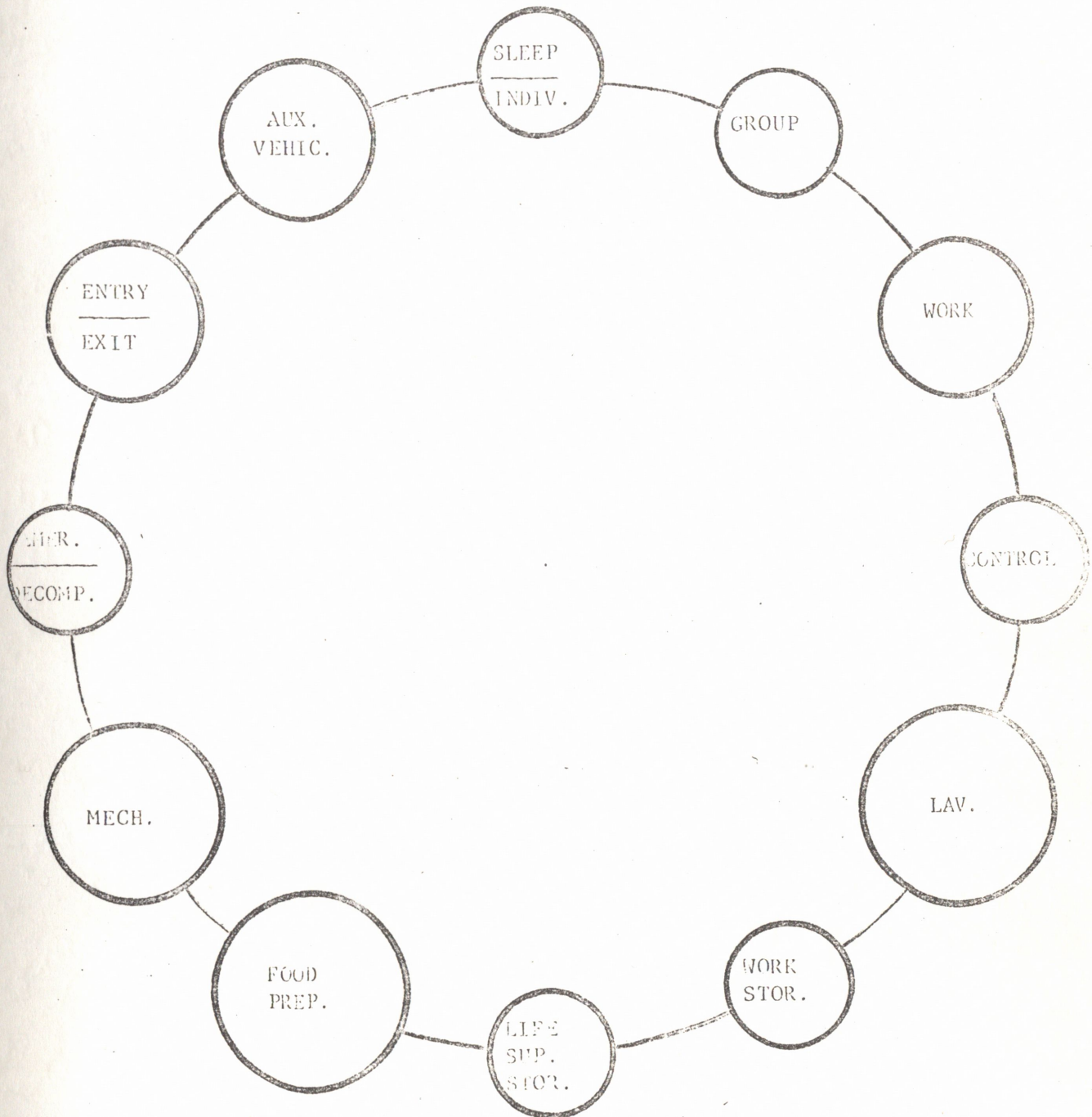
Noise production



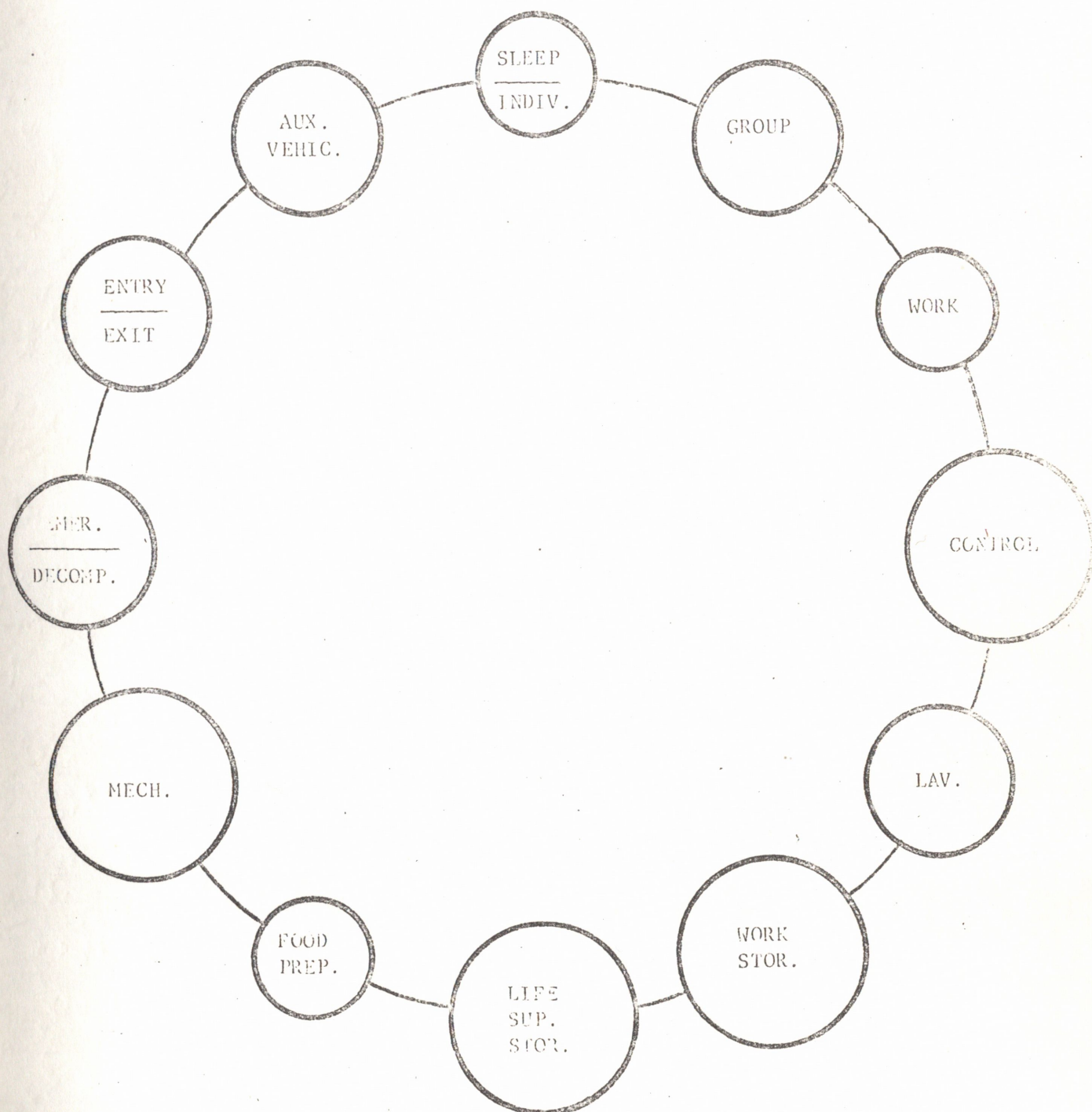
Noise tolerance



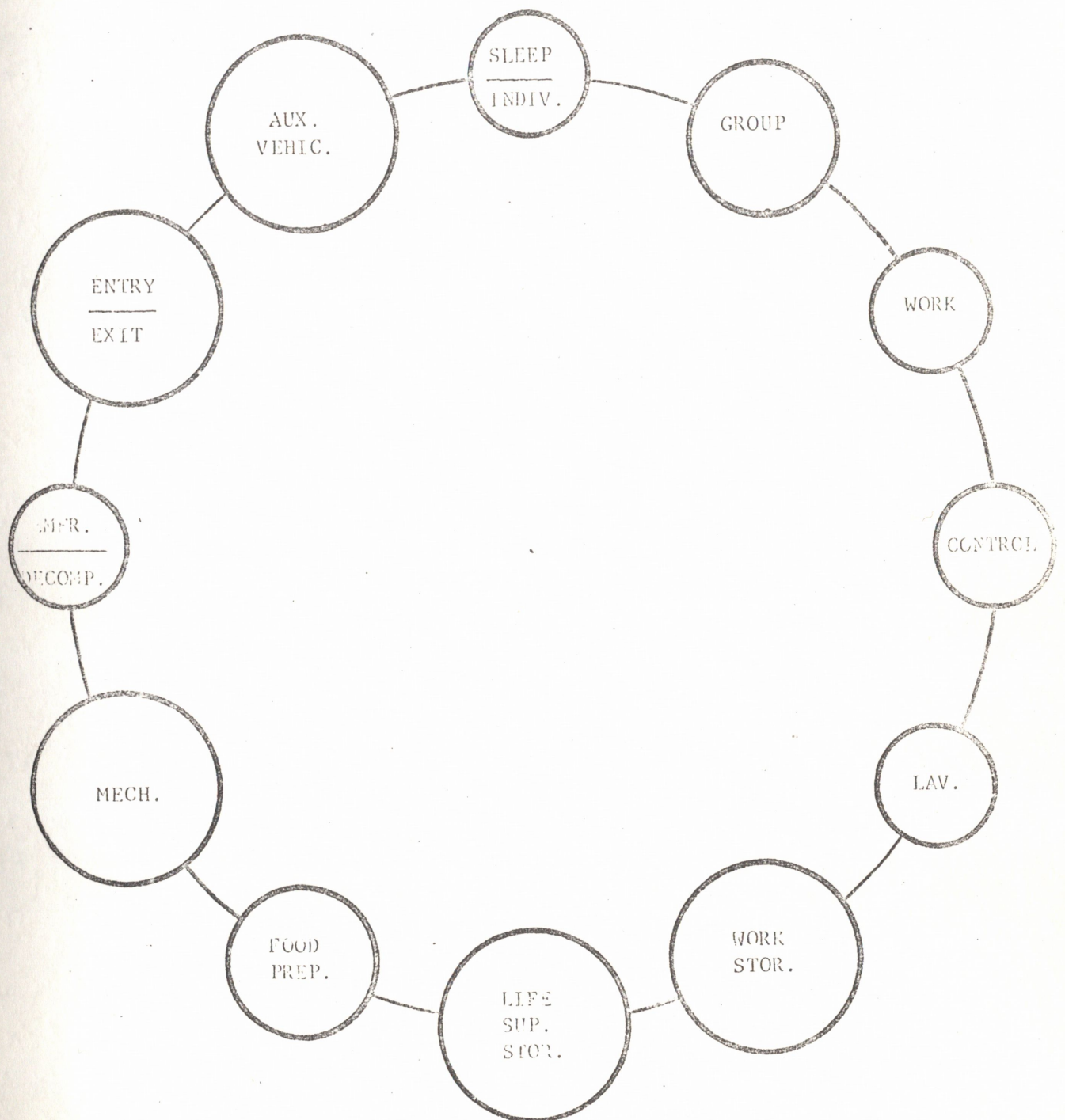
Odor production



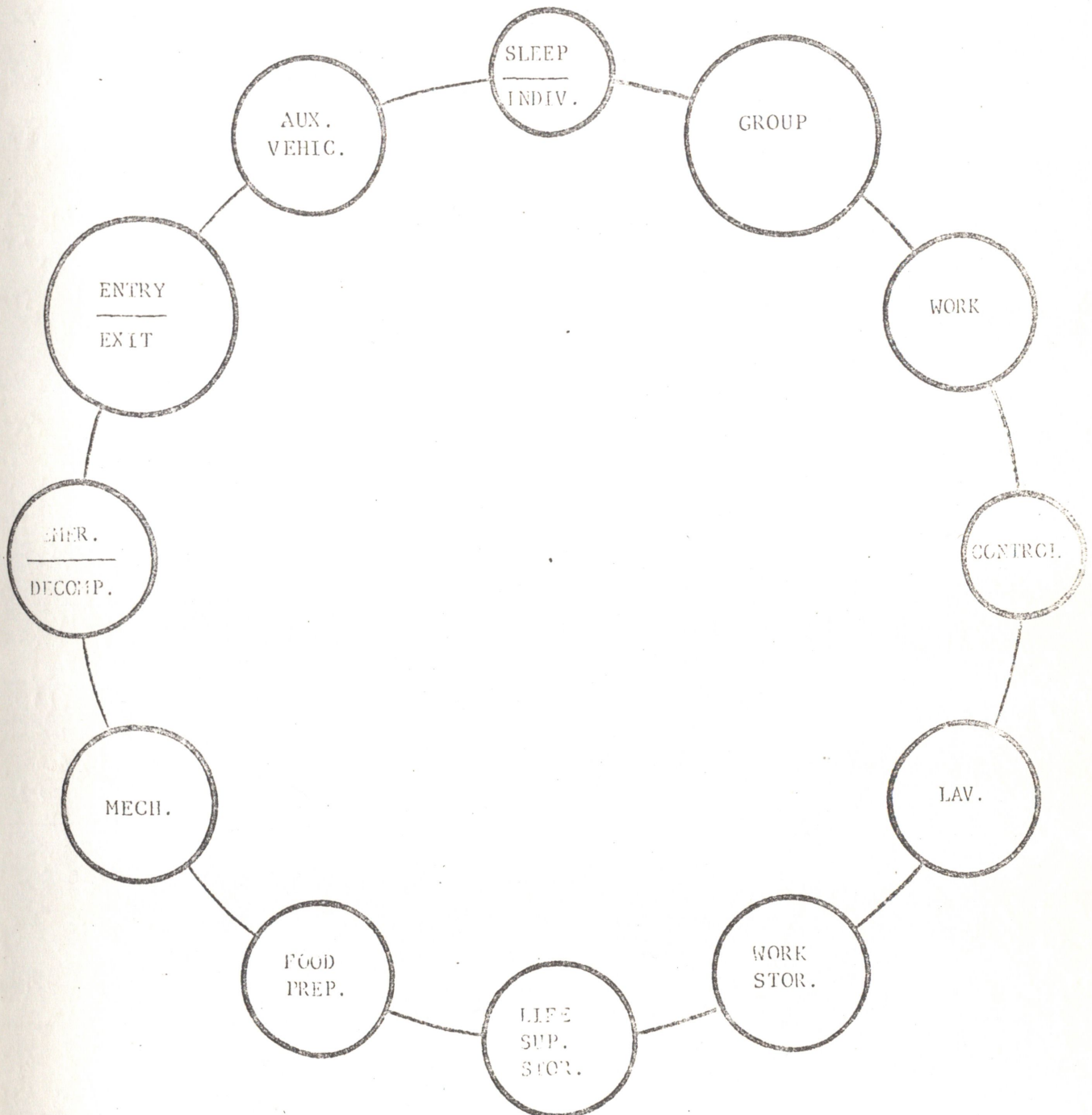
Odor tolerance



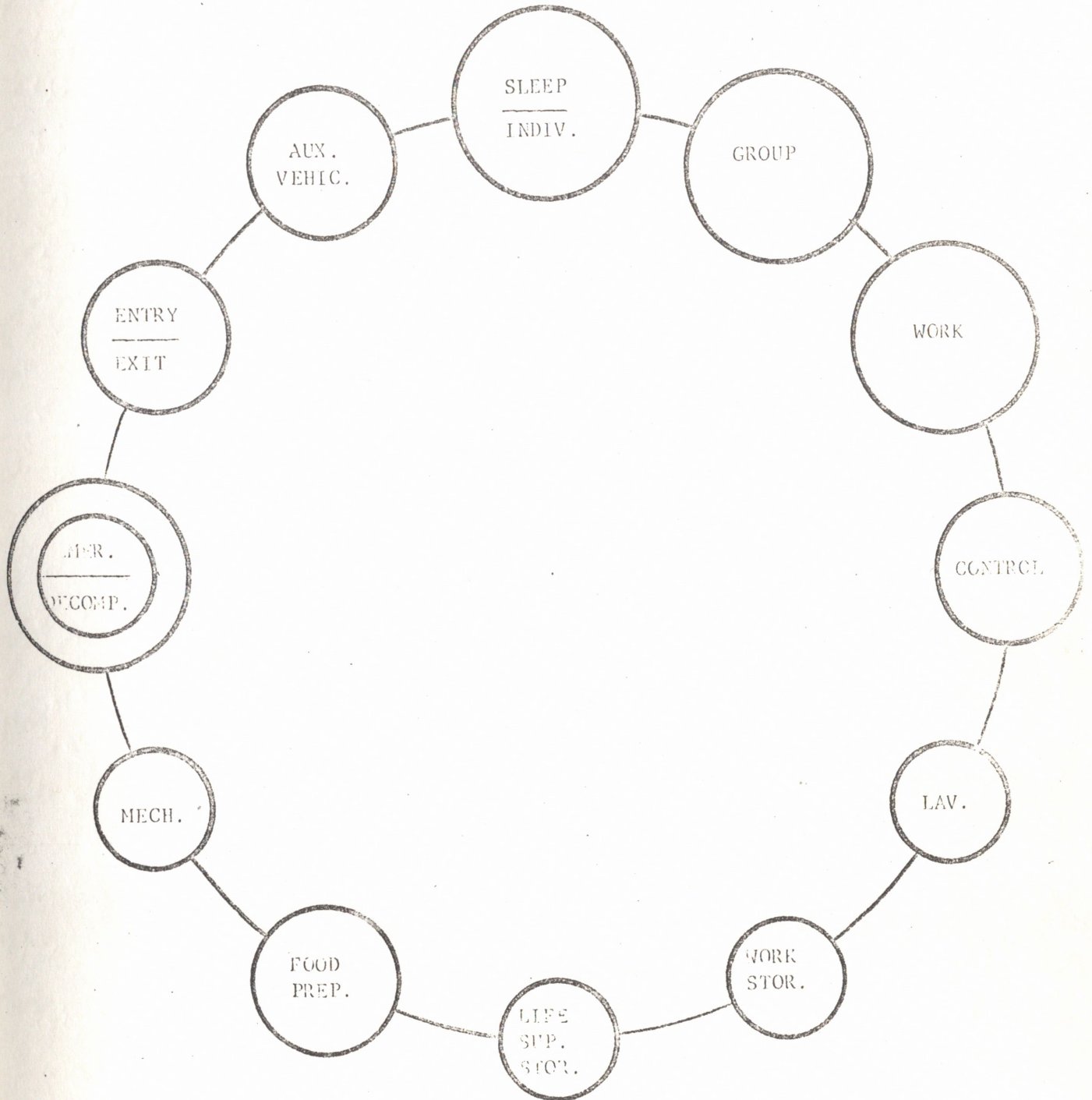
Interruption tolerance



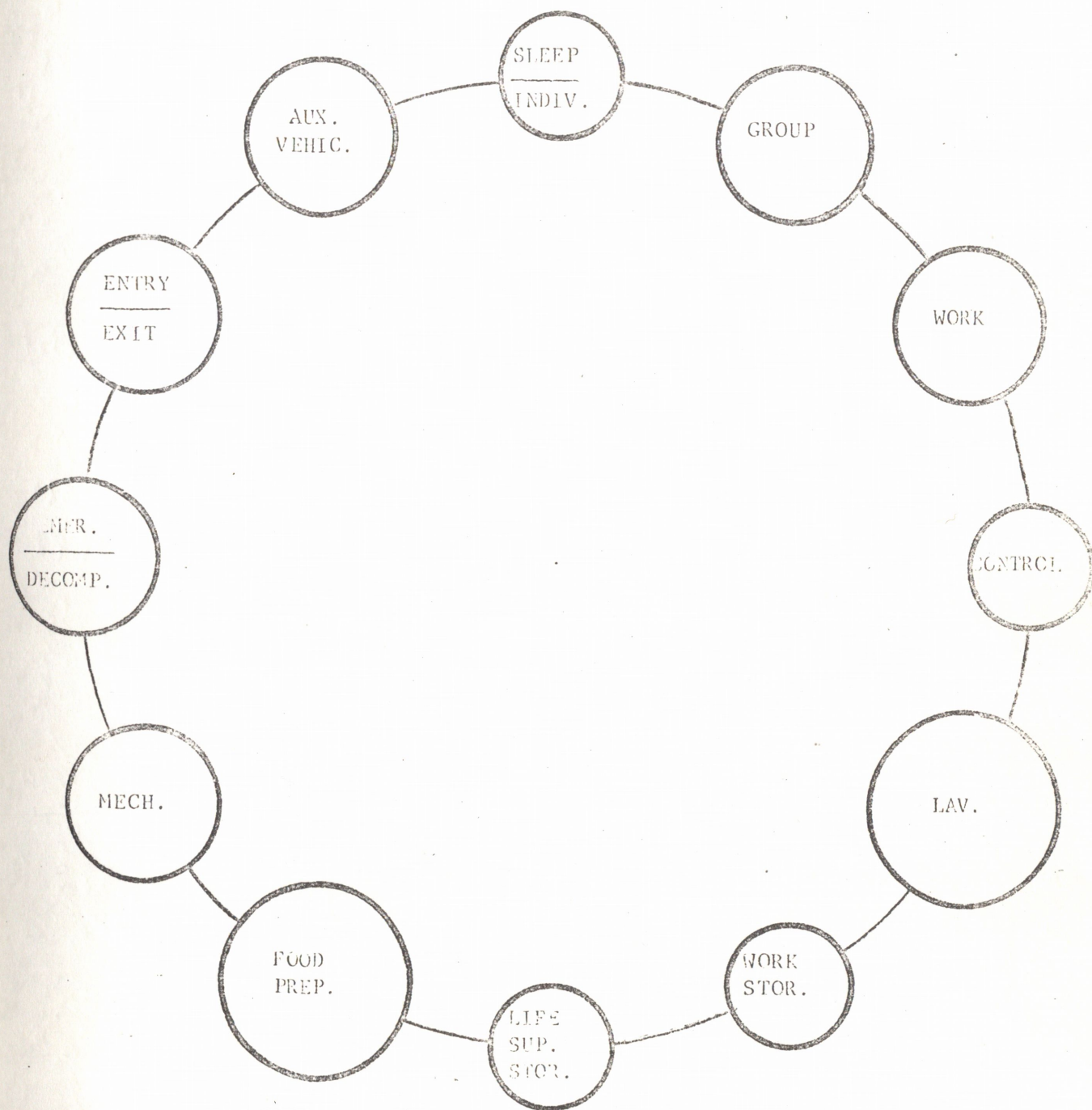
Physical activity



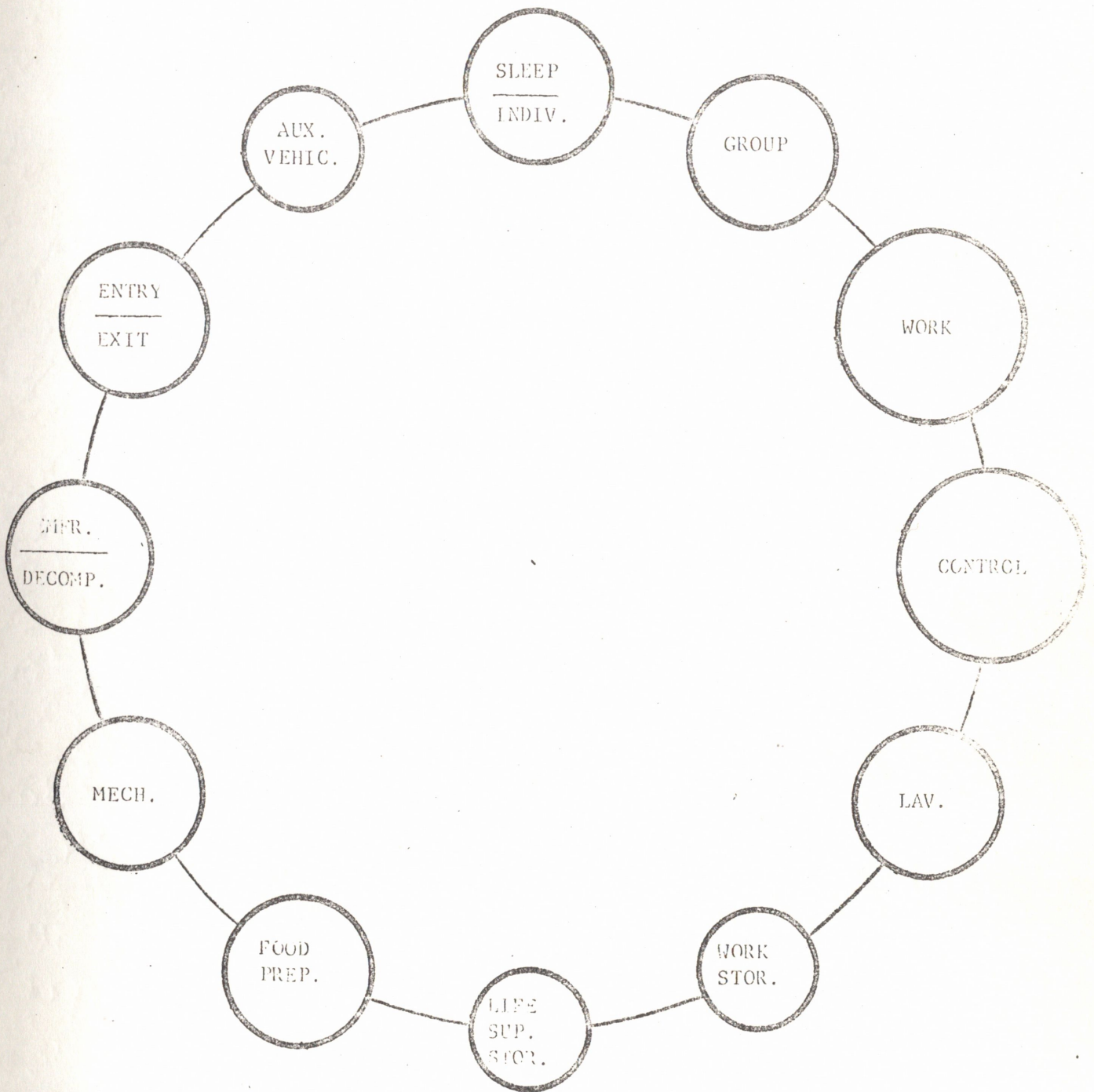
Time X occupancy



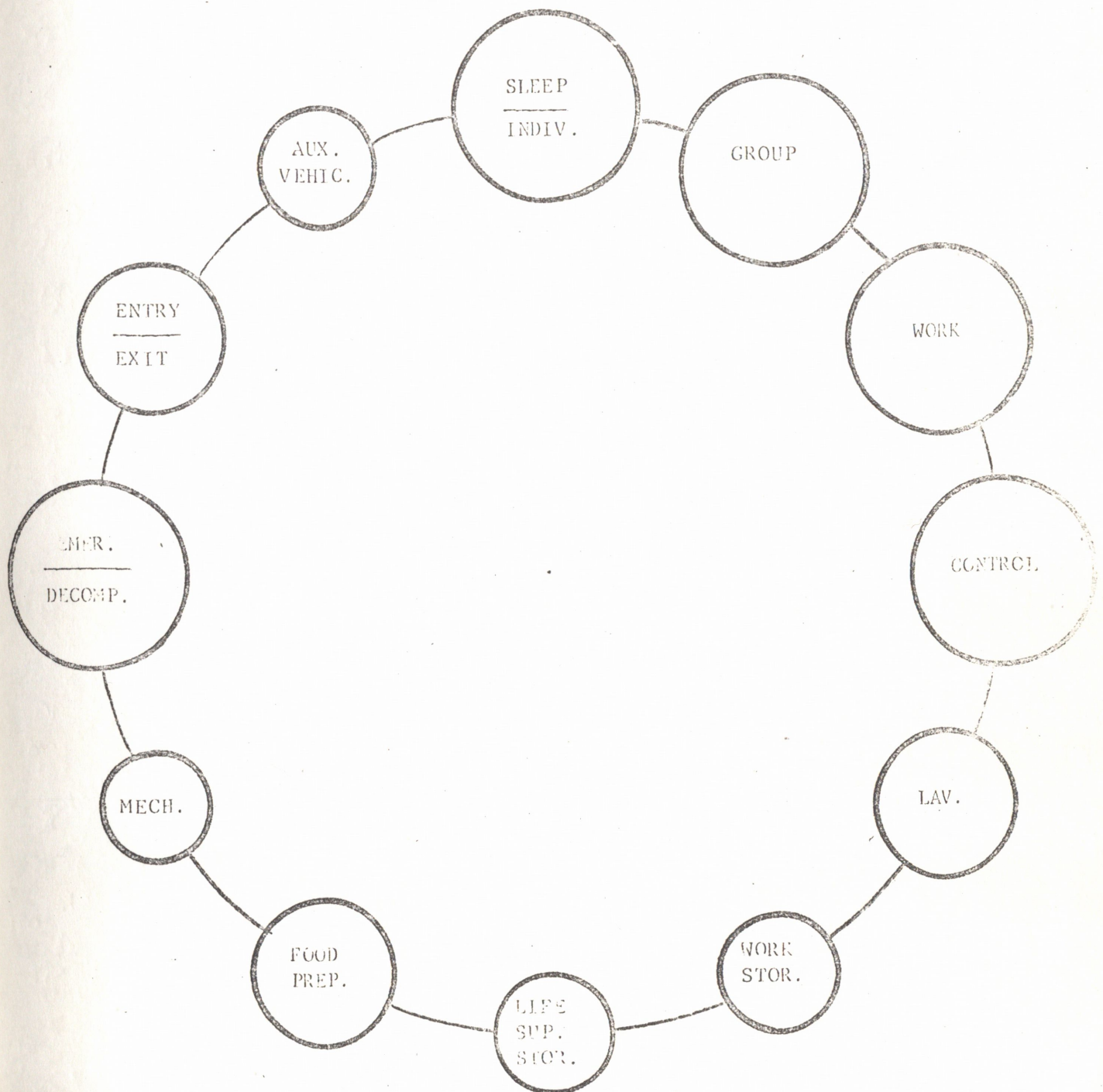
Maintenance



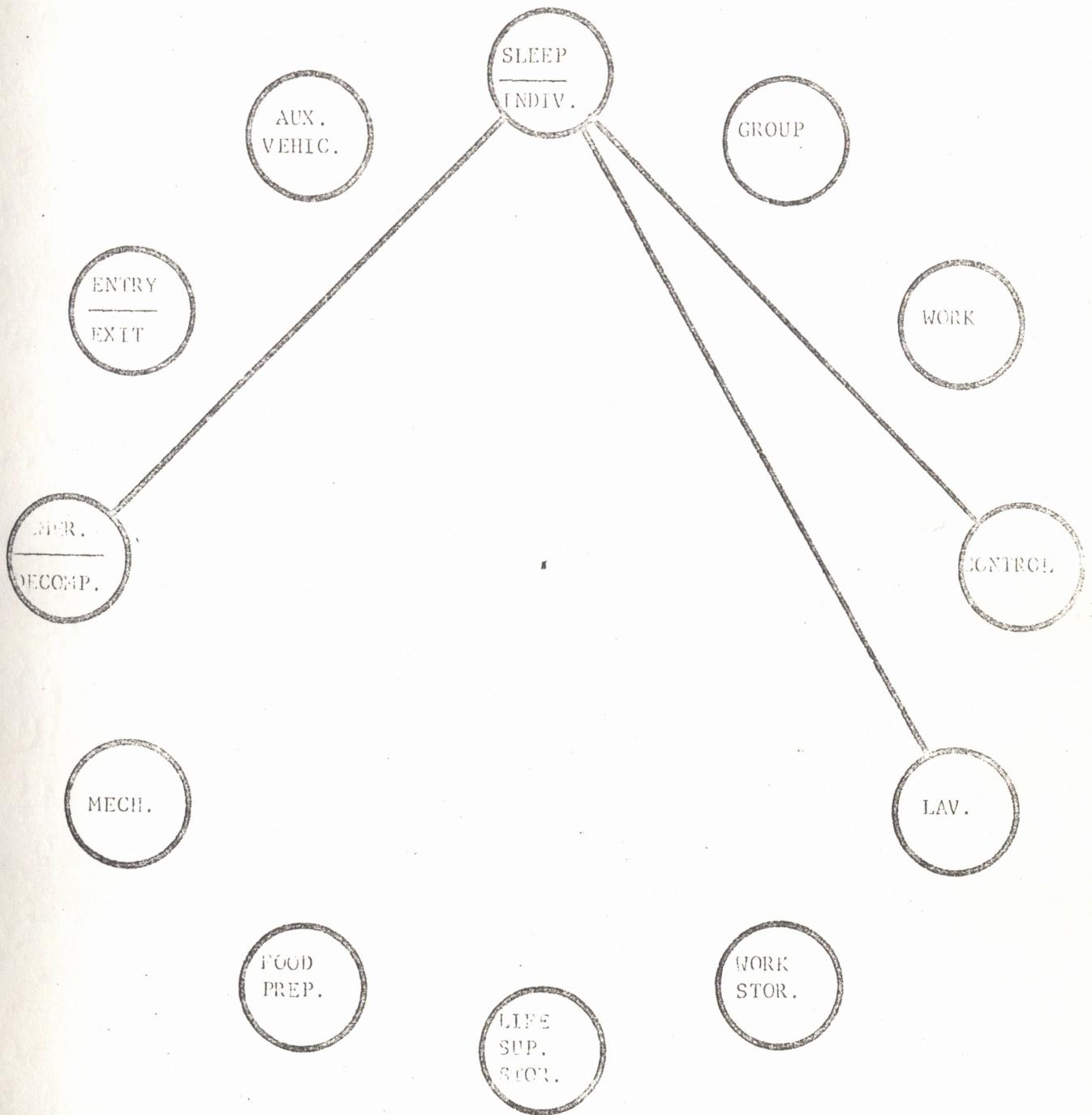
Light requirements



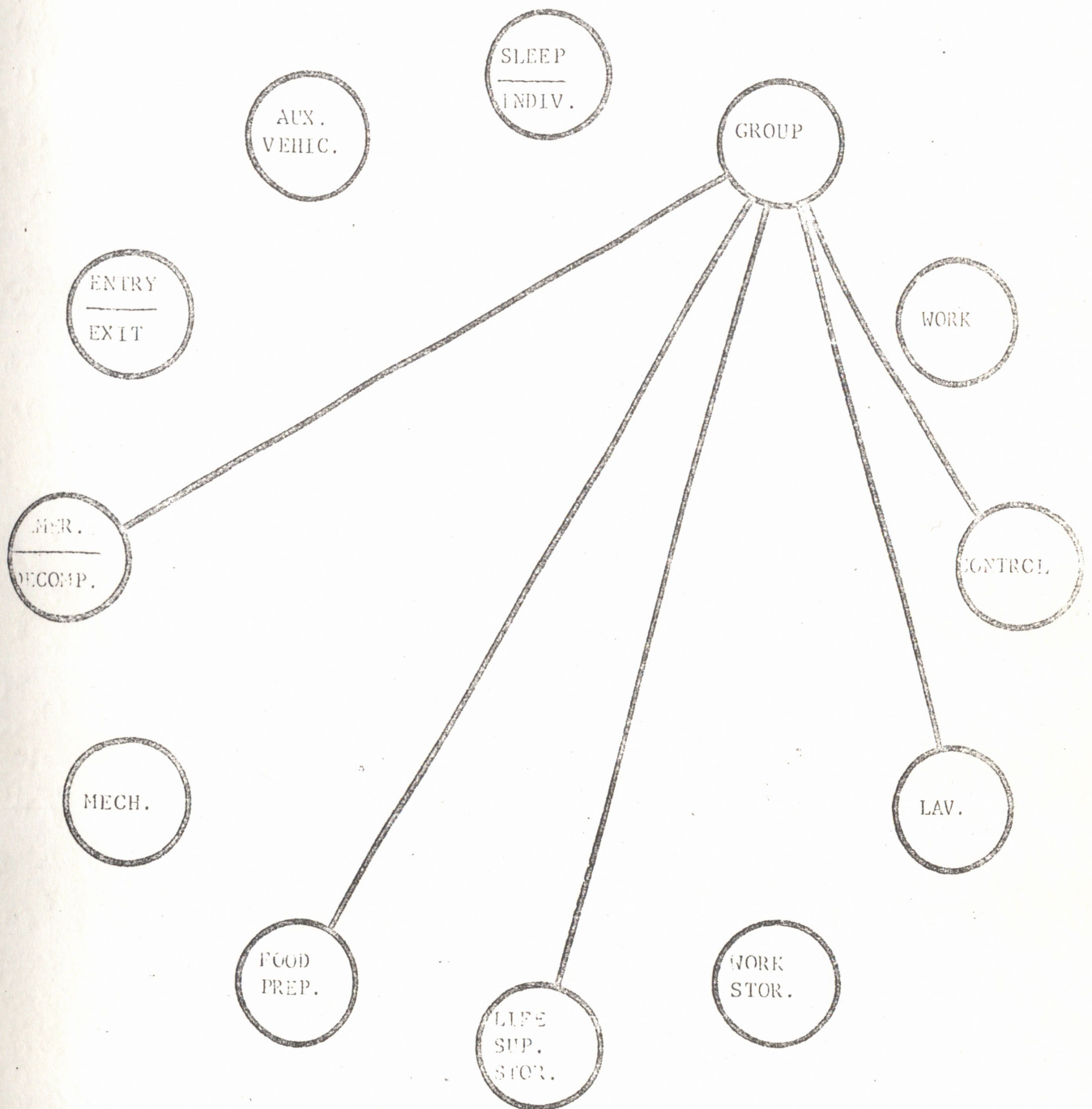
Degree of comfort



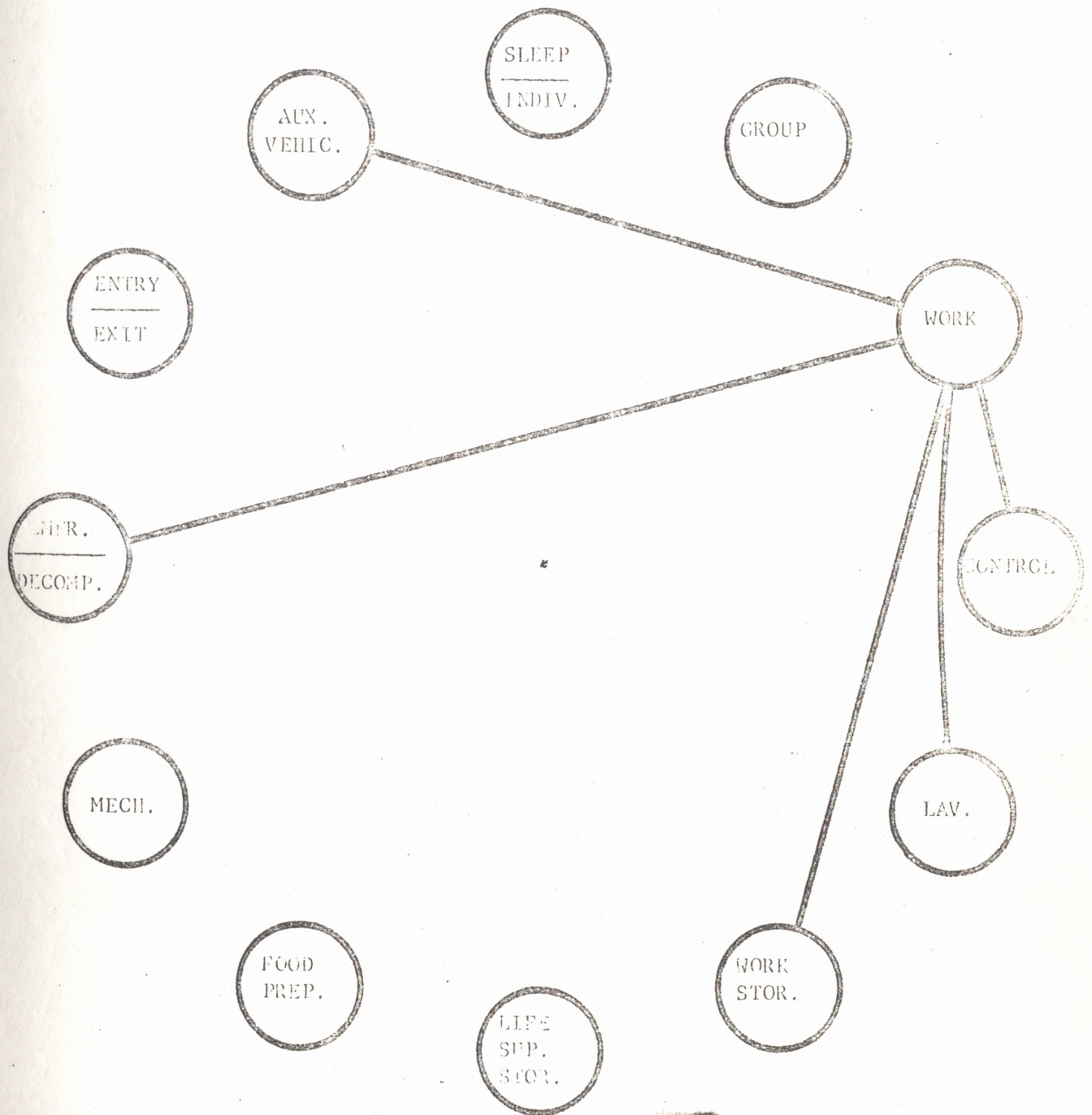
Direct connections - sleep



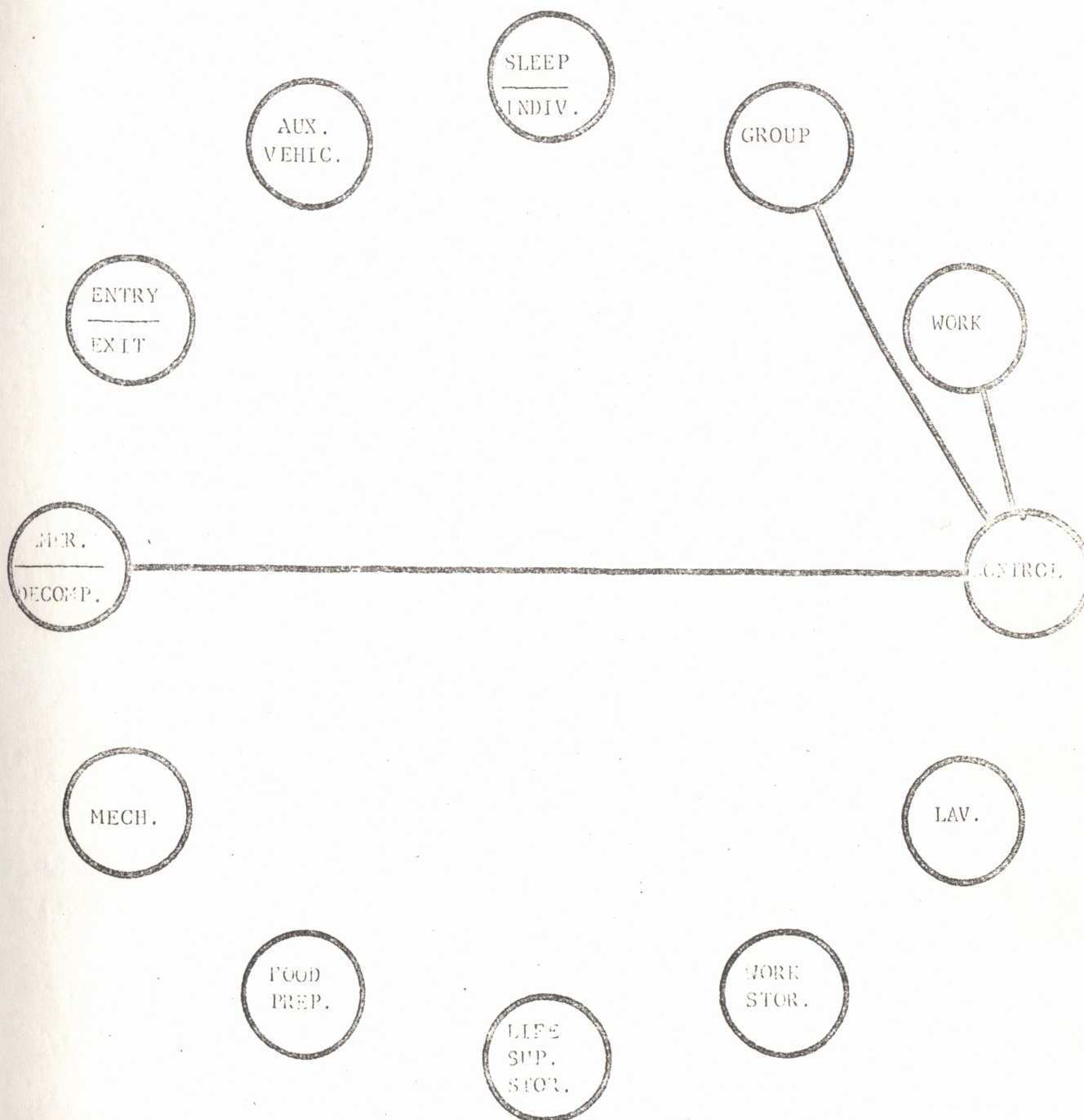
Direct connections - group



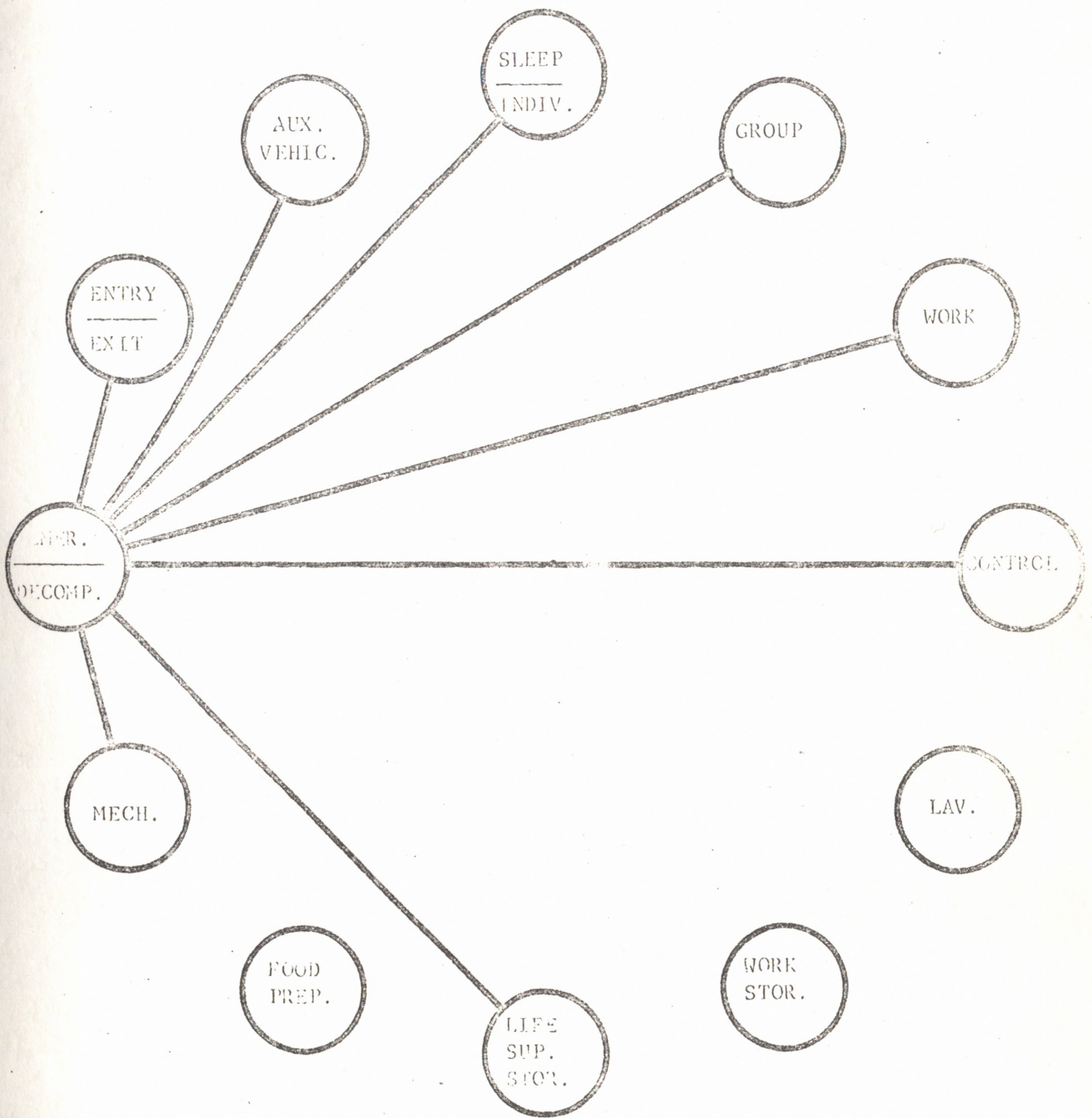
Direct connections - work



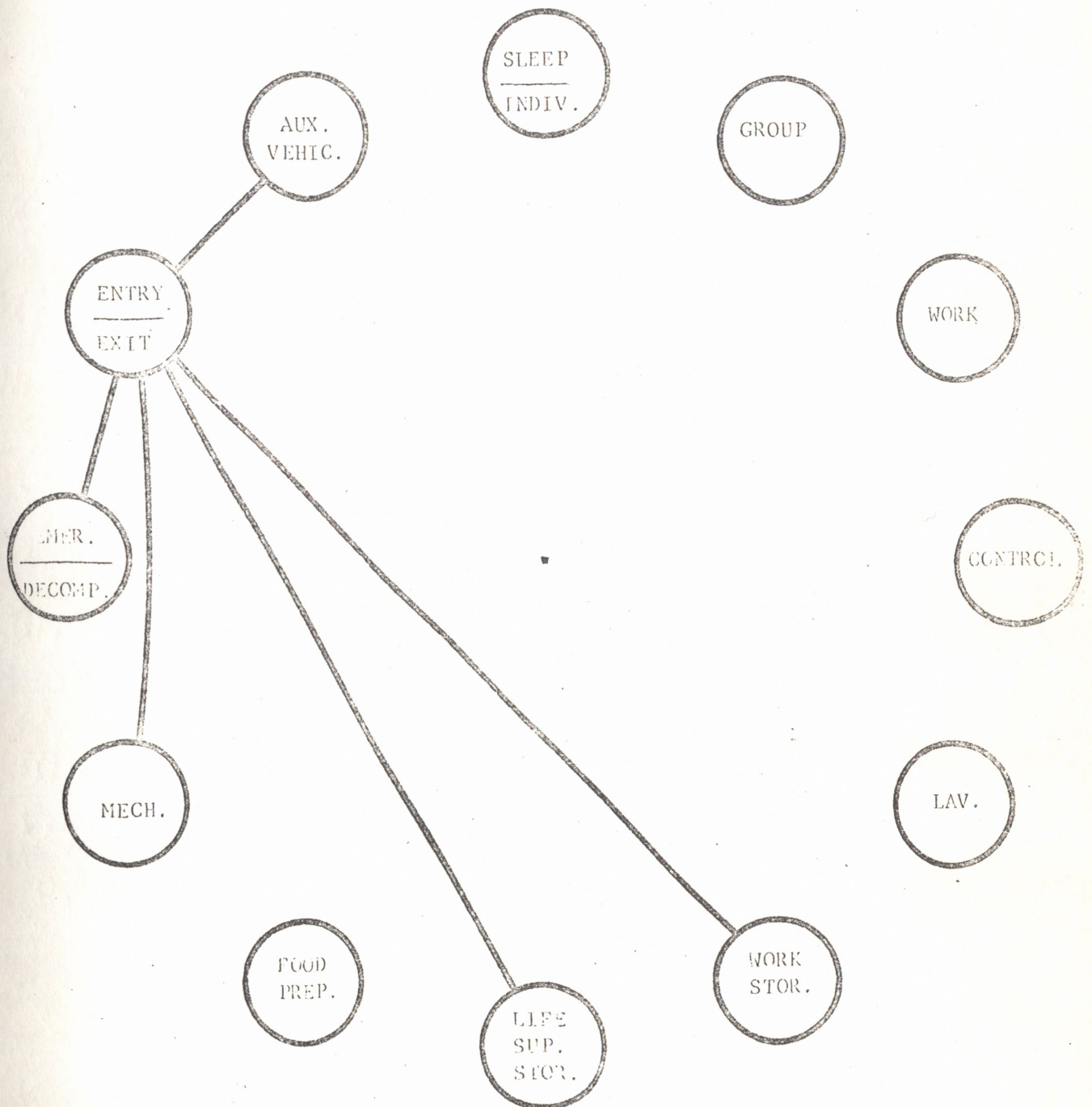
Direct connections - control



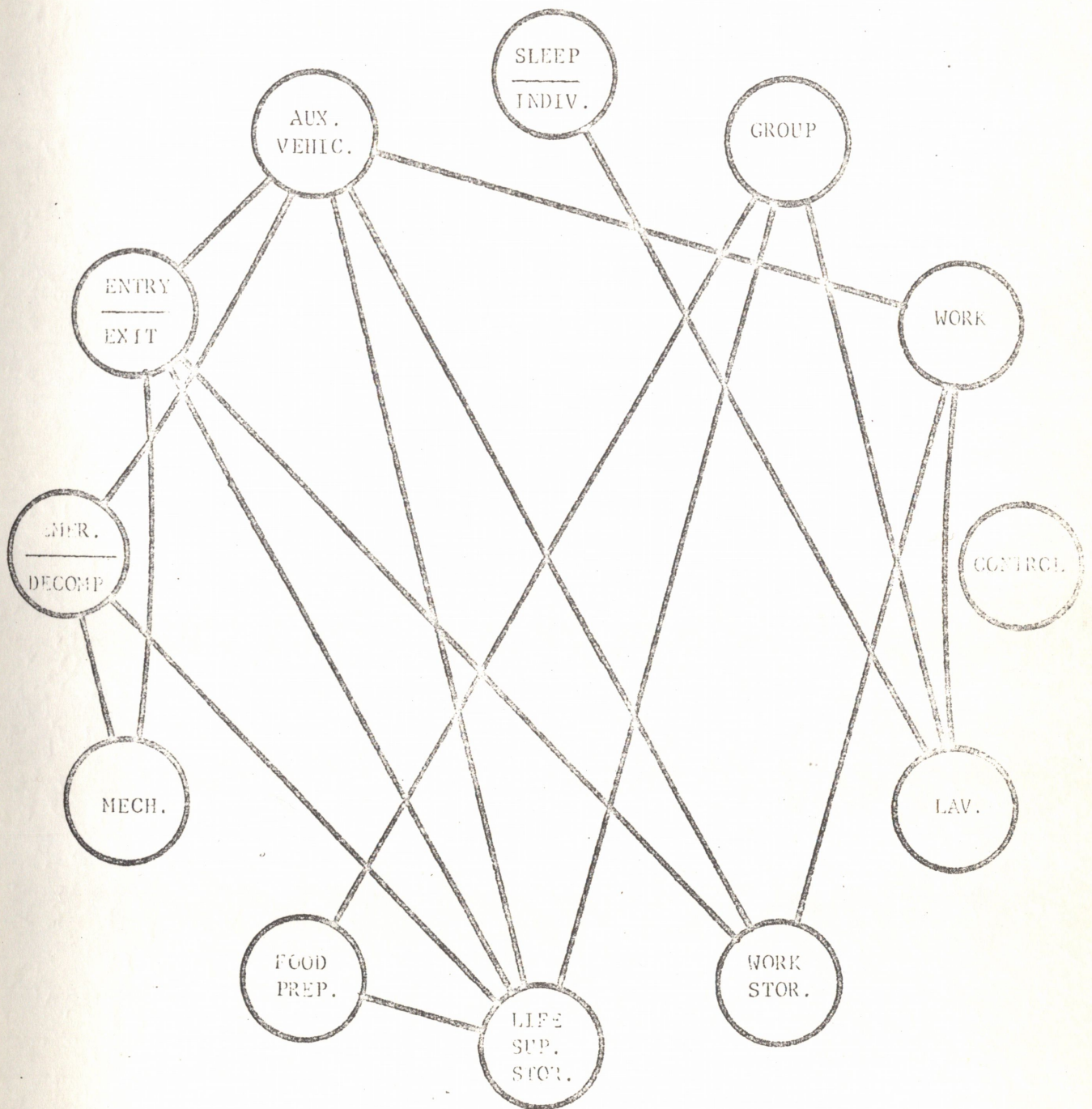
Direct connections - emergency



Direct connections - entry/exit



Direct connections - other



Structure

The major loads to be reckoned with in the design of an underwater habitat include: pressure differentials, hydrodynamic forces, impact forces, mooring loads, bouyancy and weight distribution, and internal and external functional forces.

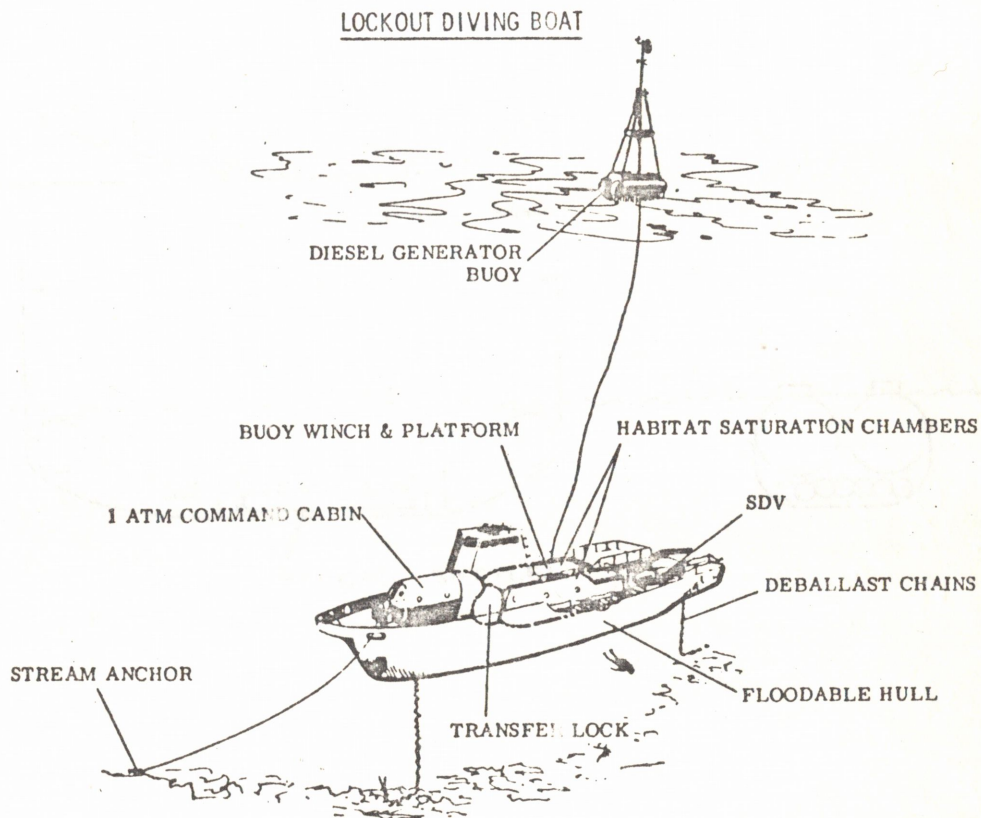
If the operation of the facility is such that no pressure differentials will ever exist between the interior and exterior, literally any shape can be used for the enclosure, since its predominant function will only be as a divider between the two media of water and gas. This is the principle upon which inflatable membrane habitats are based. However, requirements for fixed stable support for equipment, both exterior and interior, usually preclude the use of such membranes in more complex habitats. If decompression is to take place within the facility, or if it is expected to have any substantial degree of mobility, flexible membranes obviously cannot be used.

Shapes used or studied for rigid underwater structures capable of withstanding pressure differentials include the sphere, elipsoid, cylinder and torus.

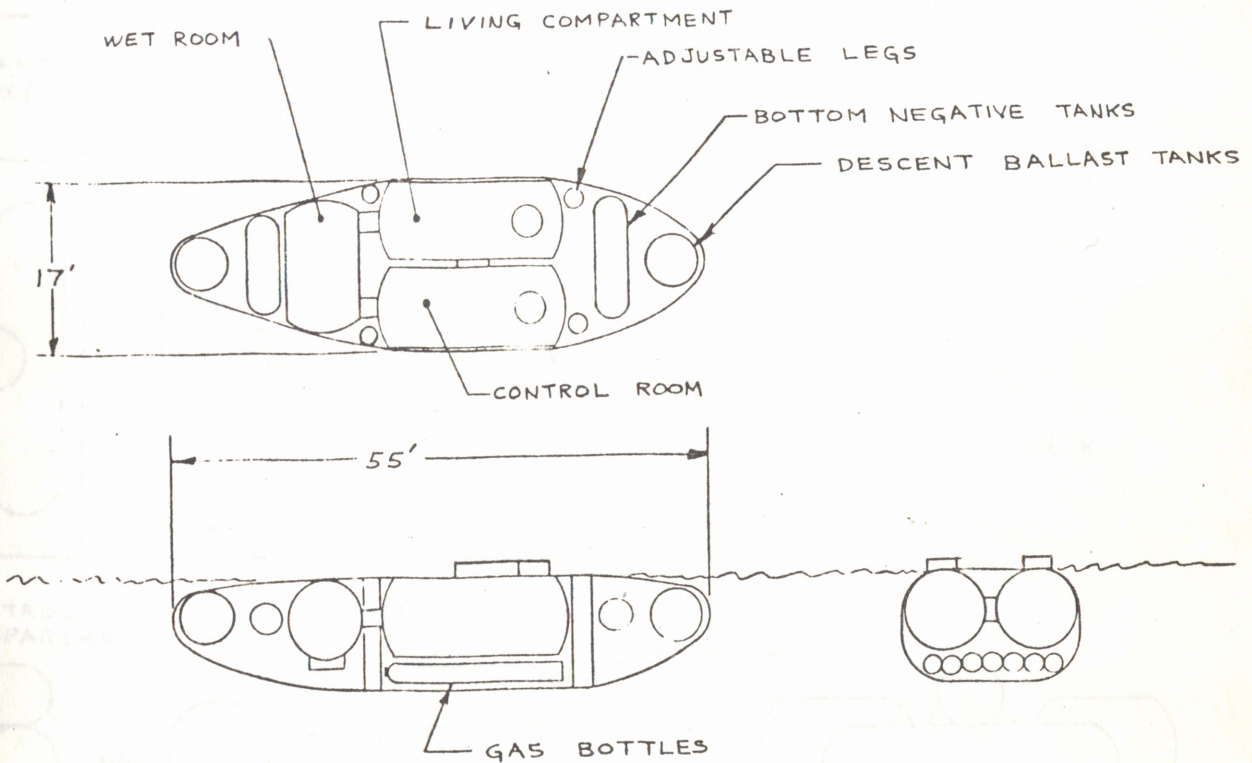
The sphere is the most efficient, using the least material for the greatest strength --- accepting very successfully the equally dispersed loads applied by water and gas pressures. For this reason spheres have been used exclusively for deep ocean work. The sphere is not particularly stable however, and its cross section sustains great resistance to movement. Shallow water habitats are not exposed to loads of the magnitude of deep ocean diving, and have as a result successfully used the various other shapes mentioned. Cylinders, mainly due to their ease of fabrication, have been used most often. The torus has

never been used in a realized facility, but has been studied --- its lack of dead ends makes it attractive in some cases. The elipsoid, closest to the sphere in its pressure accenting capacity, has been used extensively for submarines, usually in an elongated form --- its low resistance to movement a prime reason.

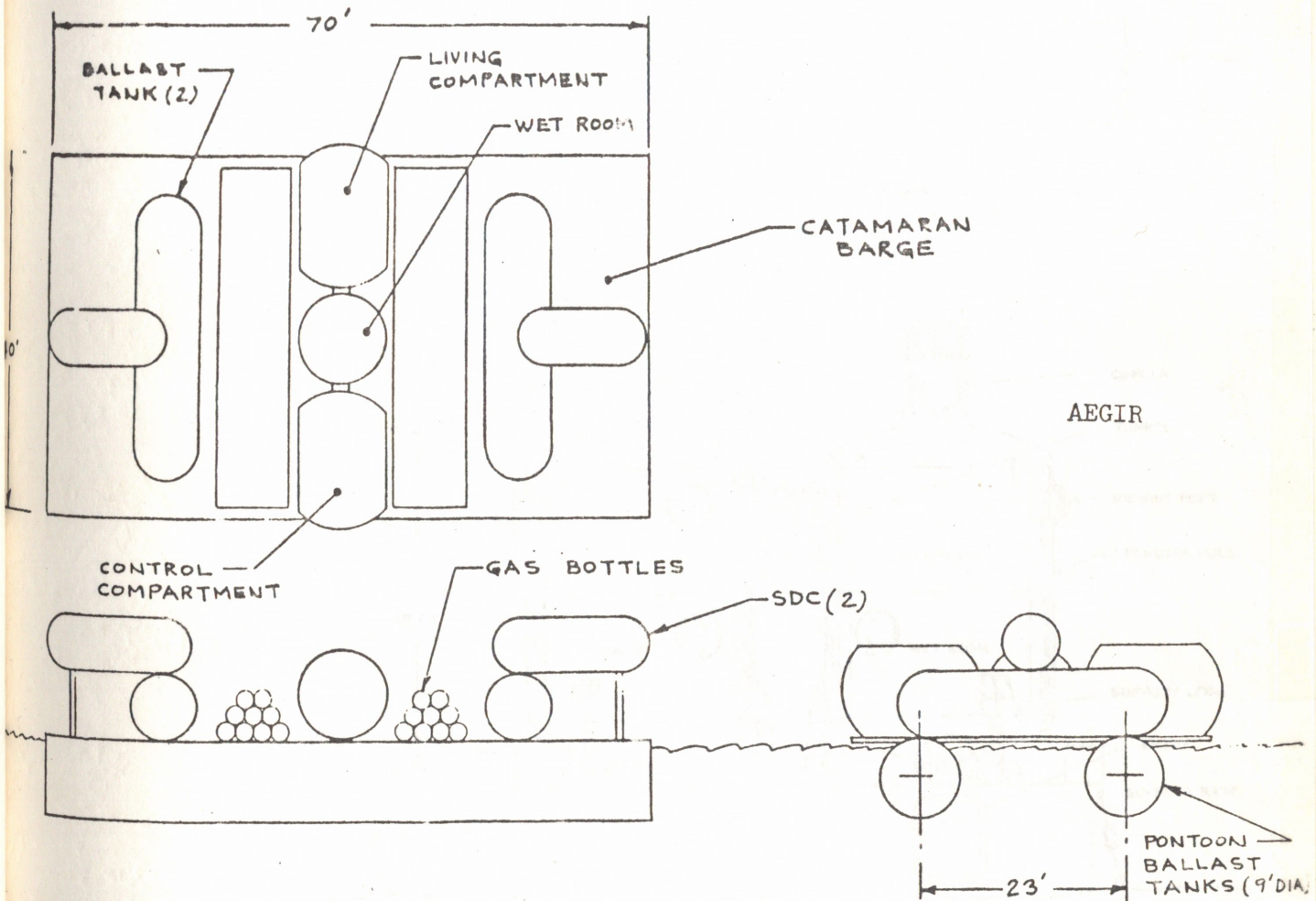
For habitats which would travel on the surface of the water, a shape similiar to a conventional ship is required for reasonable stability and ease of movement. By constructing the facility so it could travel as a conventional submarine, the ship-shaped hull would not be required.

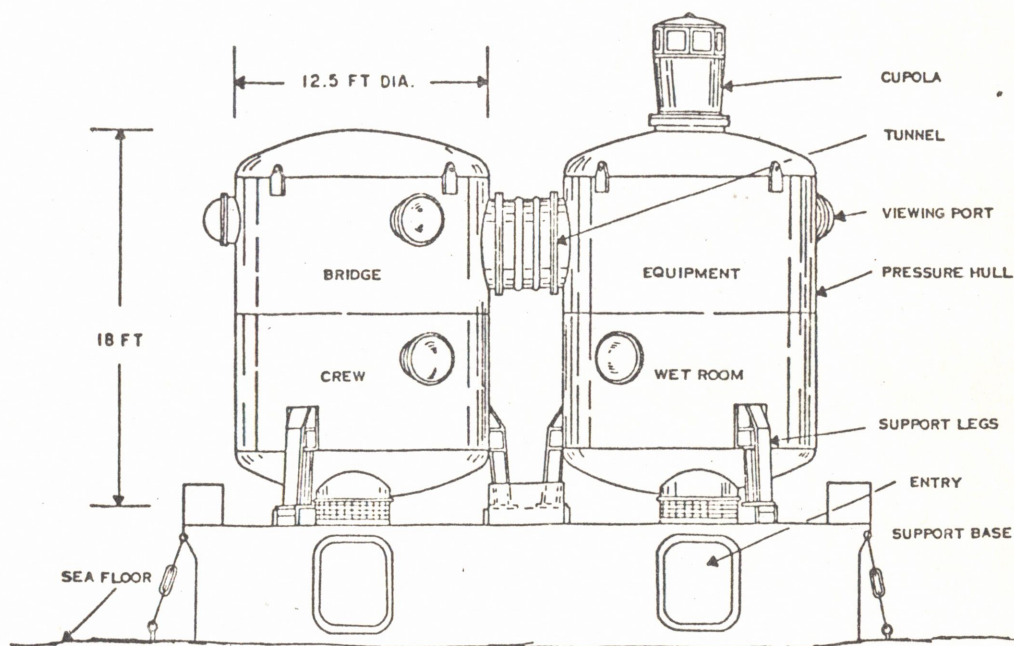
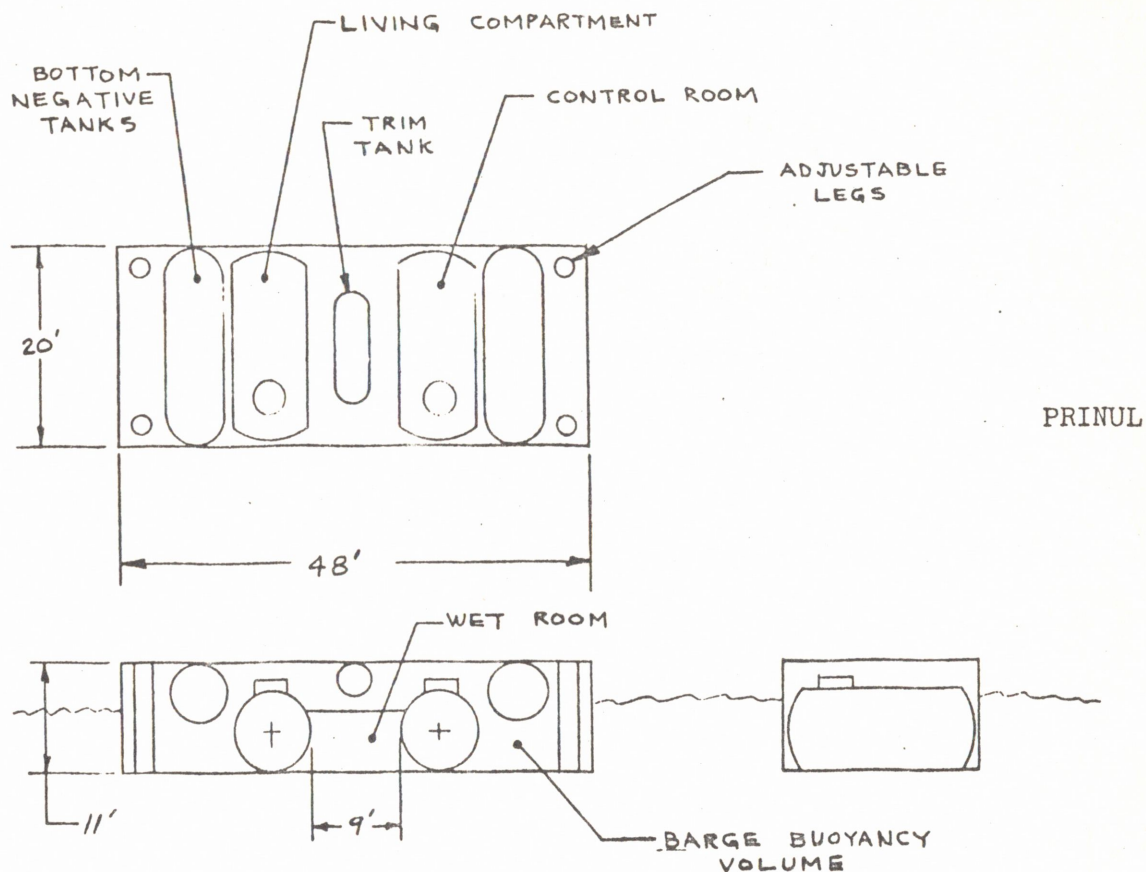


A principle which has proved successful when used for deep diving small submarines is that of using a sphere or similiar shape for the occupant space, and placing mechanical equipment in an outer shell around the habitable spheres, thus forming a finished shape satisfying stability and maneuverability requirements. The following diagram shows a study of such an arrangement using cylinders for habitable spaces.



In many previous habitats ballast tanks, gas bottles, and other items have been placed upon a sort of barge acting as a structural base for the facility. The requirement that the facility have movement capabilities similiar to those of a submarine would preclude such a non-streamlined configuration.





Side view of the TEKTITE II habitat

Means must be provided for stabilizing and securing the facility to a desired location. The use of adjustable legs has become quite popular, because it allows the leveling of the habitat on uneven ground. Explosive and deadman anchors have been used for further stability --- particularly against the heaving actions of underwater waves and currents.

Materials

Primary

Primary materials are those that are used for the structure of the habitat --- the pressure hull, supporting mechanisms, windows, etc.. Much research is currently being done to advance the state of the art for lighter, stronger materials. Numerous problems have unnecessarily occurred in underwater structures due to a lack of consideration to proper coating and material selection, galvanic corrosion, stress corrosion, and modulus differences in mating materials.

Mild steel is the primary material for habitat hulls having a design depth of 300 ft or less. It is readily available in the sizes required and is relatively easy to fabricate --- it does however require a protective coating to withstand the effects of the surrounding sea water. Mild steel has been used for the Hydrolab, Tektite, Prinul, and Aegir habitats.

High strength, heat treated HY-80, HY-100, and T-1 are U. S. Navy submarine steels having the desirable characteristics of the lesser grades of steel and in addition a substantially higher yield strength. This factor permits design to greater depths for the same weight. HY-80 with a yield of 80,000 psi is used for modern submersibles. HY-100 was used for the alvin pressure hull. (6,000 fsw). Higher strength steels such as HY-140 are being developed.

Aluminum alloys have been used in deep submergence work. The high strength to weight and stiffness ratios permit its use to depths where steel is impracticable, as evidenced by the Aluminaut design. Aluminum has increased costs of material and fabrication over steel, however.

of optical signals transmitted through the glass for control of external equipment.

Currently glass is difficult and expensive to make, and quality guarantee is nearly impossible, but the potential advantages of using glass structures in the sea are so great that considerable effort is being directed to perfect them. Glass, Pyroceram (glass-ceramic), and ceramics are being intensively studied by government and defense agencies, and also by private industry. The General Electric Company is currently studying a proposal for the use of spheres, made up of pentagonal segments of Pyroceram contained in a lattice of titanium alloy, protected externally by shells of fiberglass and titanium, at depths between 6,000 and 20,000 feet.

Acrylic plastic will find broader application in pressure hulls. It has traditionally been used for windows in submersibles and chambers, the most advanced being 4 inches in thickness with an operational depth of 1,000 feet. Acrylic hemispheres, $\frac{1}{2}$ inch thick and 2 ft in diameter, were used for view ports in the Tektite facility. This material is strong, tough, machinable, inexpensive, and has well known performance characteristics. The application of this material has been taken a step further in the construction of transparent pressure hulls for submersibles and observation chambers such as Perry's PC-8 and Link's Sea-Link.

Another plastic material which holds promise for future shallow water habitats is polycarbonate. The primary advantage of polycarbonate lies in its superior resistance to impact.

The use of concrete for submerged hulls should increase in the future because of

The stiffness of glass-reinforced plastic is advantageous and the resultant material efficiency in the composite form approaches that of steel when the glass is combined with the usual resins. The highest integrity structures using glass-reinforced plastic such as high pressure storage bottles are usually fabricated by use of wound filament techniques. These methods lend themselves to an efficient use of material and fairly simple fabrication of unpenetrated pressure hulls; however, penetrations for windows, hatches, etc. tend to raise construction costs and cause stress concentration as the filaments are wound aside to accomodate the discontinuity. It has further been reported that the basic resins (either polyester or epoxy) will not contain helium gas under pressure.

Pure glass is transparent and demonstrates superiority in corrosion resistance, compressive strength, stiffness to weight ratio and ability to contain helium molecules under pressure.

When force is applied to a crystalline metal, the atoms have a tendency to move relative to one another, a phenomenon known as slip. Slip is a major cause of compressive failure, and glass does not slip. But when glass is subjected to tension, it breaks easily. This is because microcracks or small flaws exist on the surface of the glass. By tempering, a process of heating and subsequent rapid cooling, the tensile strength of glass can be more than doubled.

Because of its great resistance to compression, glass has two other properties that might make it an ideal submarine hull. It is virtually impervious to marine corrosion, and it is transparent, offering great observation capabilities to the inhabitant. This transparency also would allow the use

the material's advantages of low cost and ease of fabrication. Concrete has excellent strength qualities under hydrostatic pressure loads and excellent durability in sea water. Concrete may be readily used for the construction of complex shapes, and wall thickness can be increased as necessary to achieve habitat neutral bouyancy without the use of additional ballast materials or massive anchoring systems. Tests have shown that permeability of seawater is not a major operational problem. A new material development presenting exciting possibilities is polymer impregnated concrete, in which plastic injected into the concrete fills its voids and results in an impermeable, stronger material.

Some habitat designs require large amounts of ballast material. This material has previously taken the form of additional steel structure, rock, concrete, cast iron, lead, steel punchings, railway car wheels, etc.. For an independently moving habitat it would be desirable to have the structure of sufficient weight to act as its own ballast, in conjunction with ballast tanks with the ability to collect or release sea water as required for negatively or positively bouyant situations.

In the selection of materials for an undersea facility great care must be taken to be sure that all materials and their connectors are not only compatible with the environment but also with each other so as to avoid galvanic corrosion.

Secondary

Secondary materials are those used for non-structural space division, living and working equipment, environmental manipulation, and visual and tactile comforts. Although they generally will not be subjected to the rigors of sea water, they are still subject to marine contamination, pressure and exotic gas effects, and must meet maintenance standards.

Habitats designed to operate in cold water or with a helium atmosphere require the application of thermal insulation to the hull walls to minimize heat loss. Insulation may be applied to the inside or the outside. In addition to providing the required insulation value, the material must in general be non-hydroscopic, non-toxic, non-odor absorbing, non-crushing under pressurization, decompressible, and retain its properties in a helium atmosphere. Sealabs I and II were internally insulated with a 2 inch layer of cork. Insulation materials such as styrofoam or urethane foam are available that have thermal conductivities much less than cork. Problems of out-gassing or crushing, however, greatly restrict alternatives. The Sublimos used 1.5 inches of sprayed polyurethane on the inside. The effectiveness of internal insulation decreases when interior walls, pipes, floors, etc. on metal-to-metal contact with the walls result in a thermal short circuit to the outside. Helgoland is now using a 2 inch external layer of sprayed polyurethane on the outside, covered with a protective fiberglass skin.

Various paints have been used and undoubtedly will continue to be used in undersea facilities. Of prime concern in choosing the type of paint are its maintainability, its resistance to wear, and its non-susceptibility to humidity, exotic gases, and ocean minerals and micro-biological life.

In Conshelf II, Cousteau's designers used smooth vinyl leather as both wall and floor coverings, and its acceptance by the aquanauts was very good. It provided a break with the cold, hard sterility prevalent in so many such projects, and was satisfactorily maintainable.

Carpet has been used in Tektite and other habitats, and has presented no problems. Contamination with microbiological organisms and dirt has apparently not been a problem.

Generally speaking, any material with reasonable durability and maintainability could be used successfully in undersea facilities. There obviously will be particular exceptions, but the field of available options has been explored very little. I believe plastics would be a particularly fertile field of investigation, due to the variety of textures and shapes that could be obtained, and the degree of durability and maintenance free use possible.

Power

Demand

The nominal power loads of various previous habitats are given in the table below.

<u>HABITAT</u>	<u>NOMINAL LOAD (KW)</u>	<u>CREW SIZE</u>	<u>MISSION DEPTH (FT)</u>	<u>WATER TEMP. OF (°F)</u>
EDALHAB	5	2-3	50	70
HYDROLAB	6	3-4	50	76
SEALAB II	39	10	200	50
SUBLIMNOS	2	2	30	32-70
AEGIR	35	4-6	500	70-80
HELGOLAND	20	4	75	57
TEKTITE	30	4	50	76
PRINUL	6	4	100	80
MINITAT	10	2	100	76

The major influences upon these power needs are crew size, water temperature, and mission parameters. The effect of these influences may be demonstrated by comparison of Sublimnos (2KW) to Sealab II (39KW). This is a difference of 20 to 1 even though the range of the crew size is only 5 to 1. This large discrepancy

is due mainly to the differing concepts of the two habitats. The Sublimos, affectionately called the volkswagon habitat, is designed for shallow water, short duration use. Its facilities are limited to minimal lighting and heating apparatus. Sealab II, in contrast, did possess all the comforts and apparatus needed for deep, long duration missions --- complete kitchen facilities, heating and air conditioning, etc..

By far the largest of all loads in an undersea facility is the environmental control system --- heaters, air conditioning units, CO₂ scrubber units, circulation blowers, and dehumidifiers. This equipment constituted approximately 50% of the total power load for Sealab and Tektite. Illumination is another major demand --- the average requirement of internal lighting for past habitats has been approximately 3.8w/ft². A self-motivated habitat will impose high demand on the power sources while in transit.

Sources

Where self-contained sources are required various power energy type sources can be considered ranging from batteries and fuel cells to closed cycle diesel engines and nuclear power.

Of the available batteries, secondary lead-acid and silver-zinc battery systems are most suitable for habitat power applications. Battery power is only feasible for low demand, short duration missions however, so I will discuss them no further.

Solid polymer electrolyte fuel cells offer the prospect of successful long-term storage, under easily controlled humidity conditions, with instant start at reduced power and full power operation a few minutes later. Use of fuel cells requires adequate storage space for reagents providing the necessary hydrogen and oxygen. Much research is being carried on at this time in the development of fuel cells --- NASA has contracted for the development of a hydrogen/oxygen fuel cell power supply for the Space Shuttle Vehicle with a life-time goal of 5000 hours, a power output of 5 KW, and a weight less than 300 pounds.

In the closed cycle Diesel system the normal atmospheric air supply is replaced with pure oxygen diluted with cooled exhaust gas or water vapor. The excess exhaust products can be voided from the system against sea pressure by means of a compressor. Storage space is again required for oxygen sources. Similar to the fuel cell, the closed cycle Diesel is an energy limited system. The closed cycle Diesel system, because of its relatively lower cycle efficiency, will require greater quantities of oxidizer than a comparable fuel cell system. (Diesel is considerable cheaper than fuel cell, however.) Typically, a 100 kw-hr closed cycle Diesel (20 to 50 KW of power) would occupy a 4 ft.

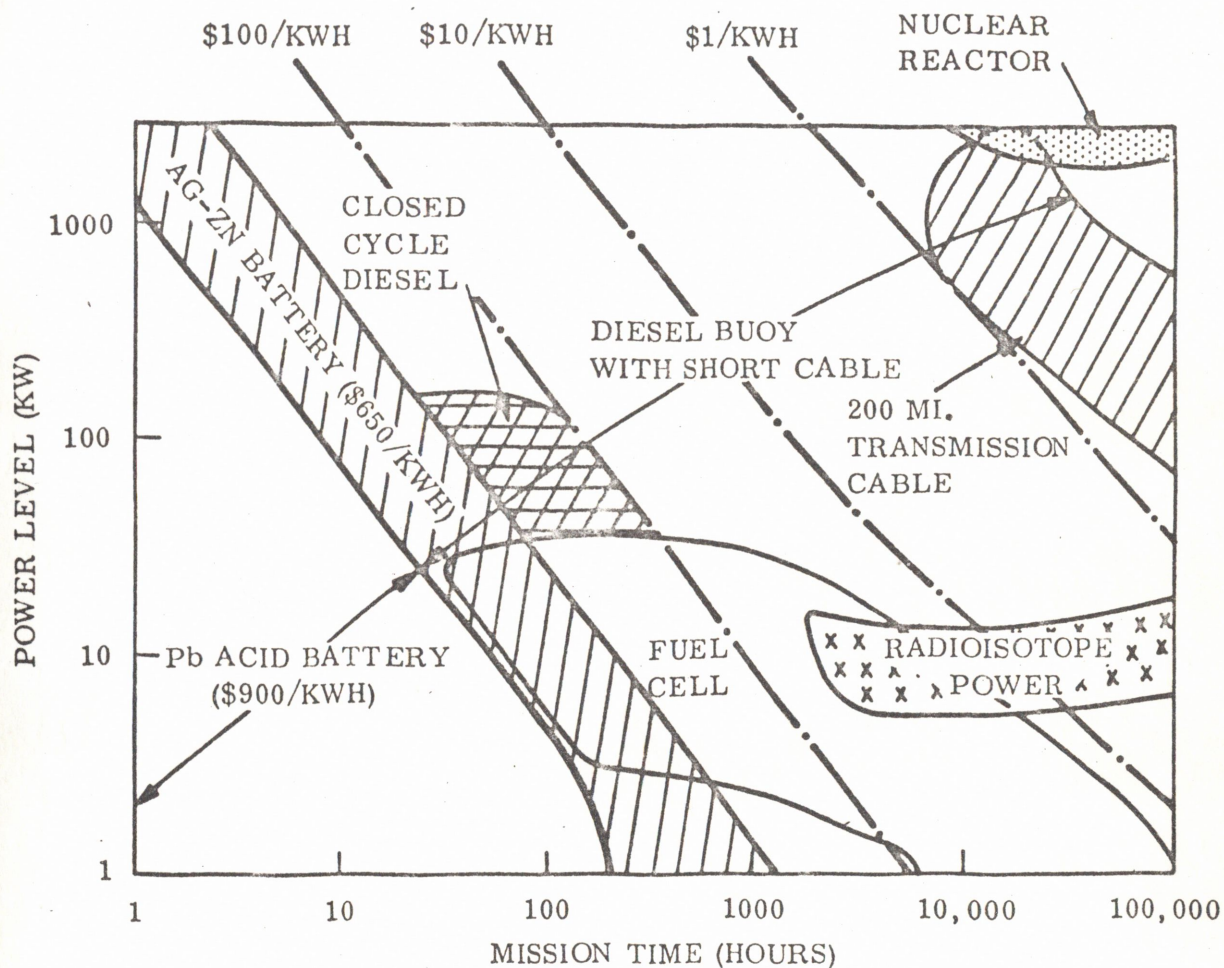
diameter by 20 ft. long pod and weigh 16,000 pounds. Included in this weight are 7,990 pounds of potassium superoxide oxygen source and CO_2 absorber and 744 pounds of fuel. With the closed cycle Diesel, consideration could be given to employing the waste heat to satisfy some of the habitat's heat load requirements.

Nuclear power sources can provide long-term habitat power, and in addition provide the thermal power needed for space heating. Nuclear radioisotope power sources can be used as a primary power source for levels up to 10 or 15 KW or as a backup electric power and heat source. The nuclear reactor power system can provide long-term power, preferably in the higher end of the power spectrum.

Long-lived radioisotopes can be incorporated in multikilowatt energy sources for habitats. In concept, the radioisotope heat source should consist of encapsulated isotope fuel, shielding, and contaminant shell. The contaminant shell protects the encapsulated fuel and shield from shock loads, maintains the shield and fuel in position, and provides protection against environmental attack. The heat is removed from the isotope source by providing coolant ducts as required by the power conversion cycle. The power conversion system which can be employed with the radioisotope sources are the Organic Rankine and the Brayton engines. A typical Organic Rankine system operating with 31 KW thermal cobalt sources provides 5 KW electric power; it can fit within an envelope of 6 feet diameter by 12 feet length and weigh 8,600 pounds. The 25 KW of heat rejected from these dynamic converters can be used for waste heat in the habitat.

The pressurized water-cooled reactor is the most suitable reactor system for a habitat power source in the near future. No reactors have been at present developed for this application. Reactor plants in the range

from 30 KW to 300 Dw of electrical power can be arranged in a verticle cylinder about 10 feet in diameter and 35 feet high. The reactor would be at the bottom, the power conversion machinery above the shield, and the controls on top. The major disadvantage of such a design is that nuclear power plants designed for much larger powers have been downgraded for this application. Perhaps a more sensible approach would be the adaption of low cost, lightweight reactors, developed for the space program, whose design has been aimed at lower powers.



Optimum Power System Regions

Life Support

Gases

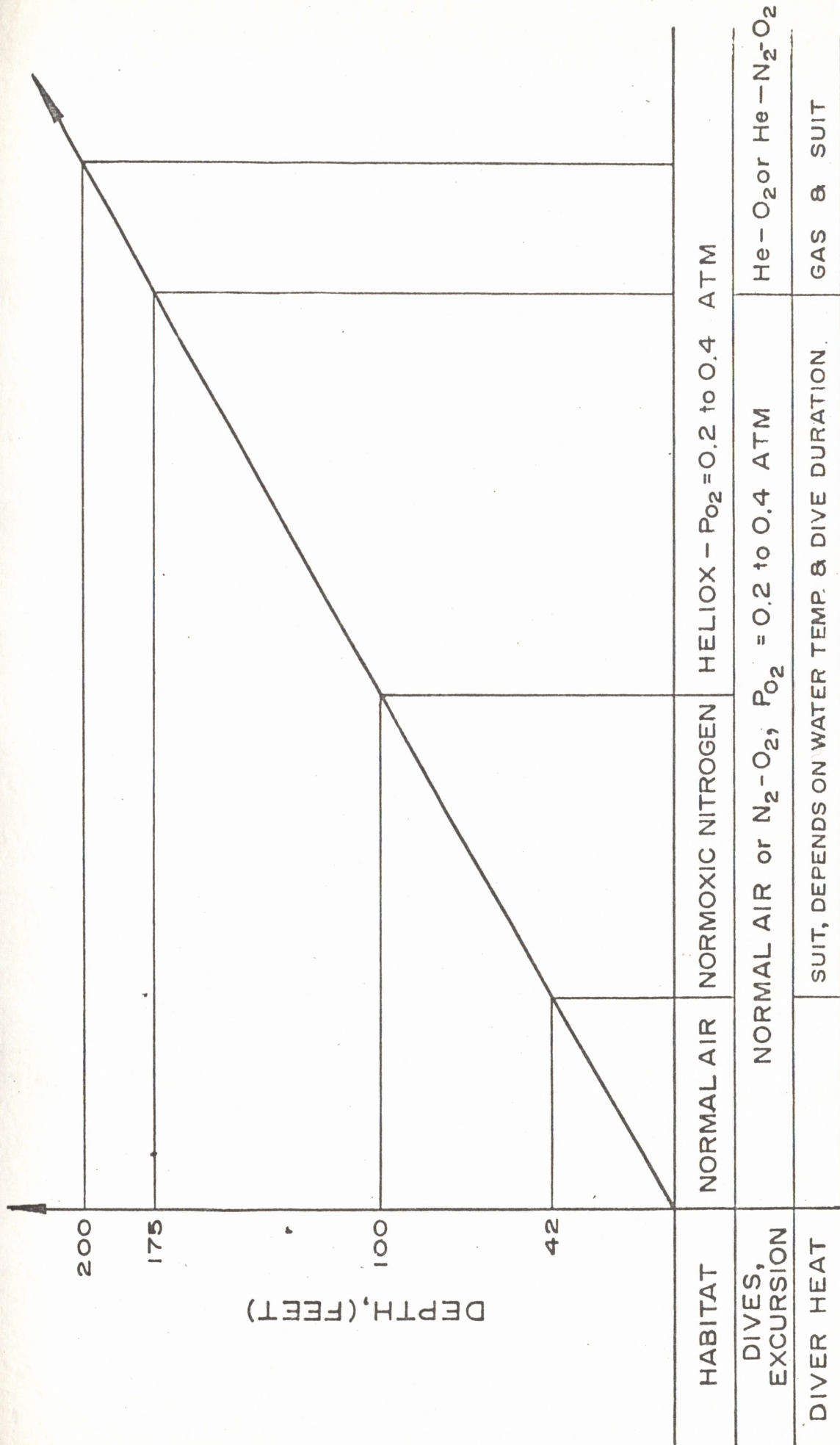
The major gases considered in undersea facilities are oxygen for life support, nitrogen and/or helium for pressure accommodation, and carbon dioxide, an unavoidable by-product.

Oxygen is the only essential gas for any habitat environment as far as life needs are concerned, for without it the human body ceases to function in a matter of minutes. Oxygen tolerance limits are well known and it is clear that for long-term exposures the oxygen pressure must be maintained between 0.15 and 0.4 atmospheres.

Nitrogen, the main constituent of natural air, is easily tolerated by man at normal atmospheric pressures. At higher pressures, the human shows a limited tolerance for the amount of nitrogen dissolved in body tissue. The result of excess nitrogen partial pressure is an impairment of certain vital functions (narcosis) which develops in a smooth progression with increasing pressure. With partial pressures of nitrogen up to 3.6 atmospheres, distinct but tolerable effects have been noted and many investigators accept this value of partial nitrogen pressure as a practical minimum for long exposures without diminishing performance in skilled tasks.

Helium has been used as a substitute or additive to avoid the narcotic effect of nitrogen at depths beyond 100 feet. However, helium has certain unfavorable characteristics, namely speech and physical effects. The helium speech phenomenon has been studied and a variety of speech processing devices have been designed and are being evaluated to see if this problem can be overcome. The physical effects stem from helium density, and specific heat. Low density reduces breathing resistance. Specific heat and conductivity affect heat transfer mechanisms

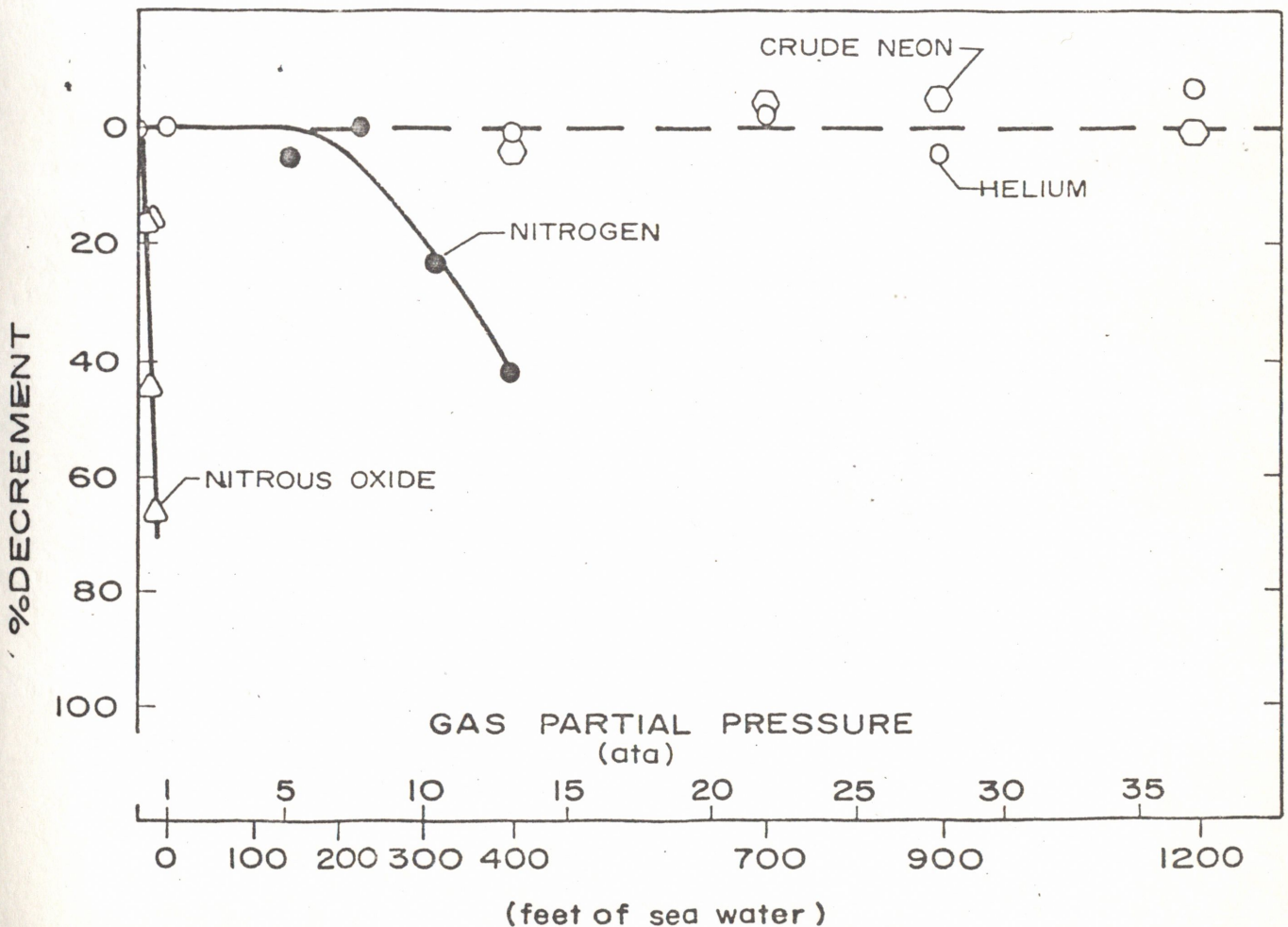
which tend to chill if the ambient atmosphere temperature is below that of the body. This latter effect can be circumvented if the gas temperature is maintained nearer 90⁸ F which essentially reduces heat loss from the body. However, heat transfer from the atmosphere of the chamber to the cold walls of the habitat is greatly increased. Therefore insulation requirements of the habitat would become more demanding. Other disadvantages of helium include its ability to permeate minute openings, its expense, and the more complex logistics of supplying significant quantities to a far-ranging habitat.



BREATHING GASES

Other inert gases such as hydrogen and neon have been considered for breathing mixtures. During the summer of 1971, a series of dives was performed at the University of Pennsylvania under the sponsorship of several different government agencies, universities and private industry. One of the participating companies conducted experiments with a crude neon-oxygen breathing mixture to a depth of 1,200 feet. Compared to helium, crude neon is more dense, and has less of an effect on speech.

INFLUENCE OF INERT GASES UPON MENTAL FUNCTIONS I. PACED ARITHMETIC TEST (MEAN VALUES IN TWO SUBJECTS)



Other than physiological requirements, gas is also required for initial charging, emergencies, and habitat purging. The initial charge is that gas which is required to pressurize the habitat to the operating depth pressure. If the volume of the habitat is large, the amount of gas can be quite great.

Emergency gas supply for breathing during atmospheric contamination is usually included in all habitat environmental control systems. In some cases emergency gas is carried to cover the possibility of habitat flooding or cutoff of normal supplies. This emergency supply should be adequate for periods well beyond rescue limits.

Purging gas is that used to replace the habitat atmosphere during heavy contamination, as by smoke or toxic substances.

Oxygen can be supplied in a variety of forms, the major ones being pressurized cylinders, liquid oxygen flasks, chemical compounds, and the electrolysis of water.

Some studies have shown that a variety of other forms can be considered if both oxygen supply and carbon dioxide removal are combined. For 100 man-day missions, the following table provides some comparisons.

COMPARISON OF OXYGEN SOURCES

Type	Weight (lbs)	Vol. (cu ft)	Cost \$
Compressed O ₂ + LiOH	2,400	28	2000
Superoxides	1,300	13	1200
Chlorate + LiOH	1,020	25	2000
LOX + LiOH	710	.27	2000

The use of active chemical systems offer certain additional advantages:

1. Superoxides also remove moisture, thereby providing some humidity control.
2. Superoxides will remove airborne bacteria and odiferous contaminants.
3. Active chemical systems are simple and reliable.

Liquid oxygen was successfully used with substantial savings in weight, volume, and cost in the Ben Franklin. The logistics of supplying liquid oxygen could pose some problems. The electrolysis of water only becomes feasible in habitat applications utilizing nuclear power.

Nitrogen can be supplied in several forms, either pressurized to as high as 6000 psig, or in the liquid state.

Helium can be supplied as pressurized gas to 3500 psig and as a liquid.

Atmospheric Purification

Atmospheric purification becomes a critically important necessity in situations such as undersea habitats --- isolation, risk in alien surroundings, and the predominantly closed cycle atmospheric conditions used are some of the major reasons.

Contamination control is usually a subsystem integrated within a larger system of atmospheric control and life support including oxygen and diluent pressure control, atmospheric circulation, monitoring, gas storage and transfer, humidity and thermal control. This is necessary to make efficient use of the available space in the habitat and to integrate subsystems that are dependent. Contamination removal subsystem approaches currently in use require circulation of the habitat gas through the control elements and, in some cases, temperature and humidity control of the incoming gas.

By carefully screening the materials and equipment used in the habitat, the sources, variety or types, and concentration levels are kept to a minimum. As a result, a system consisting of a particle filter, charcoal filter, catalytic burner, and carbon dioxide scrubber has demonstrated success in removing and/or controlling the contamination. The following table lists several applications and indicates the atmosphere purification methods employed.

CONTAMINANT CONTROL SYSTEMS USED IN EXISTING HABITATS

APPLICATION	PARTICULATE FILTER	ODOR CONTROL & BASE ORGANICS	HYDROCARBONS & CO	CO ₂ SCRUBBER
TEKTITE I & II (1969)	Yes	Charcoal	None	Baralyme
SEALAB I, II, III	Yes	Charcoal	Hopacelite Catalytic Burner	H LiOH
Hydrolab	In Air Line	Gas Purge System		
Prinul	Yes	Purafil	Yes	LiOH
Aegir	None	Purafil	None	Baralyme
Helgoland	- - -	- - -	- - -	- - -
Edalhab	Yes	Charcoal	None	None
Minitat	None	None	None	Baralyme
MK I				
PTC	None	None	None	Sodasorb
DDC	Yes	Purafil	None	LiOH
MK II				
PTC	None	None	None	Sodasorb
DDC	Yes	Purafil	None	LiOH
Submarines	Yes	Charcoal	Hopcalite	MEA

The next table presents these and other methods used to remove contaminants with a status of development.

METHODS FOR CONTAMINANT CONTROL

CONTAMINANT	METHOD	DEGREE OF DEVELOPMENT	REMARKS
O ₂ Control	Charcoal	Standard Use	Some hazard due to flammability in hyperbaric chambers. Also removes trace organics
	Purafil	Standard Use	Standard use. Also removes trace contaminants from metabolic processes, cooking and some carbon monoxide. Sensitive to moisture
	Aluminum	Available	Absorbs large molecule contaminants but does not remove methane.
Particulate Matter	0.3 micron Filter	Standard Use	Commercially available.
Hydrocarbons & CO	Hopacelite Catalytic Burner	Standard Use	Performance degrades with moisture. Less effective removing methane. Freon & other contaminants decompose resulting in the release of toxic gases.
CO ₂ Removal	Baralyme Sodasorb	Standard Use	Standard use in habitats & closed and semi-closed breathing apparatus.
	Lithium Hydroxide standard grade	Standard Use	Standard use in habitats & decompression chambers. Dusting & crusticity are problems.
	Lithium Hydroxide dust-free grade.	Limited to experimental testing.	Coated to eliminate the dusting problem. Not specifically used in diving applications currently.
	Potassium Superoxide	Application in mine rescue and fire fighting equipment.	Control of pO ₂ at depth, chemical contamination & moisture control are problems. Removes CO ₂ and generates oxygen.
	Lithium Oxide LiO ₂	NO SIGNIFICANT DEVELOPMENT	
	Barium Hydroxide Ba(OH) ₂		
	Sodium Hydroxide NaOH		
	Magnesium Oxide MgO		
	Magnesium Hydroxide Mg(OH) ₂		
	Calcium Oxide CaO		
	Calcium Hydroxide Ca(OH) ₂		
	Sodium Peroxide Na ₂ O ₂	Designed & built for use in space simulators. Some foreign evaluation	Performance degrades in presence of organics & moisture. CO ₂ must be vented over-board.
	Lithium Peroxide Li ₂ O ₂		
	Molecular Sieves		
	Monoethanolamine (MEA)	Used successfully in nuclear submarines	Efficient system. Some problem with the release of toxic vapors. MEA is a strong alkaline solution. Some operation instability due to oxidation.
	Sulfate-cycle	Feasibility testing for submarine use.	Use for oxygen production & carbon dioxide absorption.
	Ionics Exchange Absorber	Prototype testing for submarine use.	Used for oxygen production & carbon dioxide absorption.
	Algae Culture	Experimental Testing for submarine use.	Used for oxygen production & carbon dioxide removal. High electrical power requirements.
	Polyethylenimine PEI-600	NO SIGNIFICANT DEVELOPMENT	
	Amberlite IR-45		
	Epon 562/Det		
	Cryogenic CO ₂ freeze out	Equipment built and tested to date has proven unsatisfactory	Problems are logistics, of supplying the cryogenics, & insulation effectiveness humidity control problems.

All particulate matter that will damage the pumps, impair the operation, or unnecessarily increase the task of a component by clogging or contamination is removed from the habitat atmosphere by a filter. Particles large enough to damage the human lung must also be removed. Absolute filters capable of removing particles down to 0.3 micron are usually installed in the inlets of the atmosphere circulation ducts to satisfy these limits.

Charcoal filters have been used extensively in commercial and military applications for removal of various contaminants. Because of its flammability, charcoal may be hazardous in high oxygen hyperbaric atmospheres, particularly in active systems where the gas is blown through a granular bed. For this reason, Purafil has been used more extensively in recent habitat designs. Purafil is an activated alumina compound impregnated with potassium permanganate which will remove several acid alkaline gases and oxide unsaturated materials.

Hopcalite catalytic burners are used to remove hydrogen, carbon monoxide, methane, and other hydrocarbons that pass through carbon filters. The burner oxidizes the contaminant at a high temperature in the presence of a catalyst. The water vapor and carbon dioxide products are subsequently removed by other subsystems.

Carbon dioxide is removed from the breathing gas by chemical absorption, chemical absorption with oxygen generation, chemical absorption with regenerable compounds, chemical absorption with molecular sieves, or cryogenic freeze-out methods.

For the chemical absorption method, three different caustic materials, lithium hydroxide, Baralyme or Sodasorb, can be used, but extreme care must be taken to avoid contact with the skin and eyes and to avoid breathing the dust.

Filters are used to contain the dust particles. Scrubbers employing these chemicals have proven to be simple, reliable, and relatively low-cost.

Several superoxides and peroxides not only readily absorb carbon dioxide but simultaneously produce oxygen. Various materials have been tested and used since 1904 in both undersea and space applications. Potassium superoxide is used in mine rescue and fire fighting apparatus for individual life support.

Chemical absorption with regenerable resins is based on the reaction of the highly basic organic compounds with carbon dioxide to form carbonates. At elevated temperatures, the reaction is reversed, thereby regenerating the material for subsequent reuse. Liquid resins have been used successfully both industrially and on nuclear submarines. Problems are contamination by resin, low regeneration percentage, release of toxic vapors and causticity.

Molecular sieves are chemical absorbers made from synthetic zeolites (metal ion aluminosilicates) which have a high affinity for carbon dioxide, water vapor, and other substances. They are regenerated by heating and purging or by application of vacuum.

Cryogenic freeze-out of carbon dioxide is frequently utilized in commercial and scientific air separation processes by cooling the gas stream to a point where the carbon dioxide freezes. The solid carbon dioxide is allowed to either adhere to the heat exchangers or is collected in a filter trap as a solid. Regenerative heat exchangers must be used to minimize refrigeration requirements of the unit. Exhaled gas must be dehydrated prior to entering the heat exchanger to prevent clogging in a relatively short period of time.

After leaving the heat exchanger, the gas must be heated and rehumidified for personal comfort of the diver. No significant application and success of this approach has been evident for diving or habitat purposes.

Temperature - Humidity Control

Having accommodated the basic life function requirements (oxygen and pressurizing inert gas), the next most important function of any atmospheric control system lies with regulation of temperature and humidity. Increasing depth and decreasing water temperature add to the complexity of this problem.

There are so many variables that affect the system design that no clear cut case can be presented. Perhaps the best way to illustrate this is to tabulate those variables having major affects:

1. Habitat proper
 - a) volume
 - b) contents (electronics, lighting, etc.)
 - c) number of occupants
 - d) length of mission and mission characteristics
 - e) power sources
 - f) insulation
 - g) vapor sources (cooking, showers, etc.)
2. External surroundings
 - a) water temperature
 - b) water depth
 - c) water current
3. Power supply

There do not appear to be any constraints as far as state of the art is concerned except perhaps in the area of habitat insulation.

Humidity control is necessary from a systems standpoint as well as a physiological one. Electronics, electrical motors and components, grounding, shorting of contacts, etc. are all sensitive to high humidity and condensation. The methods of moisture removal range from simple chemical absorption using various drying agents to more sophisticated air conditioning systems, where moisture is removed by condensation.

Temperature control will vary from conditions where sensible heat will have to be removed to maintain a comfort level, to cases where the need will exist to supply heat. If the habitat is to be adapted for both extremes, a heat pump system or equivalent will have to be given consideration, whereby the atmospheric control system can provide heating as well as cooling.

Water System

Water for undersea facilities can be obtained through an umbilical from shore or surface, by producing potable water from sea water and/or waste water, or by storage for the duration of missions in or near the habitat.

A surface supported habitat will normally get its water from a surface supply through an umbilical and carry on board a day tank or other emergency water supply in the event of some disconnection from the surface.

Self-sufficient habitats, such as the Helgoland, carry water in flexible rubber bags in fairings outside the pressure hull. Bouyancy changes that would otherwise result from water consumption are prevented by allowing salt water to compensate for the volume change of the rubber bladder tanks holding the fresh water.

Desalination and reclamation have the disadvantages of increased system complexity, additional power requirements, higher costs, and the need for space aboard the habitat. But for sizable independent operations for extended periods of time they become the only feasible method of maintaining an adequate supply.

Increased atmospheric pressure and the use of exotic gases has not affected the water distribution systems or water quality of past habitats to my knowledge. Distribution systems within the facility should pose no significant design problems abnormal to similar systems in surface applications. Some means of maintaining a constant hot water supply must be provided.

Food

Various different methods of storage and preparation of foods have been used in previous habitats. In Sealab II, the food was of the canned, heat-and-eat variety. While these meals were nutritious, there were complaints about Sealab being a "feeder" and the meals were monotonous. Problems were also encountered with cans subjected to high pressures. Frozen foods were also used to a limited extent. On Conshelf III, the six crew members ate frozen dinners similar to "TV" dinners. Canned juices were available and were stored external to the habitat in a wire pantry. There are many varieties of marine life fit for human consumption. It is not recommended that a mobile research facility be designed dependent on the sea as a food source, however, because the availability will vary with location, season, and a myriad of other determinants. This is not to prohibit the use of sea sources when possible or desirable.

Tektite II provided an opportunity to collect and evaluate data on food preferences and food management in a unique environment, monotony as a function of food type and variety, food preservation and handling, efficiency and accountability, and techniques for measuring food intake and energy expenditure. Seven hundred and twenty-six man days of food intake were required to support this seven month program. The core menu for the first series of dives was composed primarily of pre-cooked frozen food. Core menus for subsequent dives had an equal mixture of precooked frozen, dehydrated, and thermo-stabilized foods. Food systems which included a variety of food types had a significant effect on food monotony --- longer periods of time were required to detect food monotony.

Based on food consumption studies, sufficient food should be provided for four meals a day. In an effort to avoid monotonous meals, it has been recommended that two meals be frozen and the remaining two be either canned or

freeze-dried. Frozen meals offer a wide selection of food with little risk of contamination. The waste disposal problem is greatly alleviated because the used trays can be replaced in the freezer and removed at resupply intervals. This also reduces the quantity of dishes that must be washed. Freeze-dried foods require no refrigeration and are reconstituted by the addition of water.

Disposable utensils met with a negative psychological response, and thus are not recommended. The same held true for TV dinner trays. The use of substantial, reusable tools will impose greater maintenance loads, but this is not seen as a major problem. In large habitats a full time cook would be required anyway, and this further alleviates maintenance problems.

To handle food storage, in habitats, freezers, refrigerators, and cool dry storage space must be provided.

To keep the time required for cooking at a minimum, an infrared or microwave oven can be utilized. While these units reduce cooking odors, they should be enclosed with an odor control hood. Electric burners should also be provided for heating of food. All cooking and water heating could be done in closed vessels to reduce the humidity released into the habitat atmosphere.

All cooking mechanisms should have controls and monitors designed with problems introduced by pressure, gases, or contaminant release in mind.

Sanitary System

The main sources of waste aboard underwater habitats are human waste, water effluent from showers and laundry, kitchen waste and chemical wastes resulting from laboratory work. The prime sources of kitchen waste are garbage, packaging, and water. Garbage and packaging cannot be feasibly reclaimed within the confines of the facility, and thus must either be destroyed or stored for eventual removal. For sizable missions of extended duration using storage as a means of disposal, a compaction mechanism is recommended. Destruction always entails the production of secondary material such as smoke or ashes, resulting in further removal problems, and to my knowledge has not been employed to any significant extent in any facility. The use of such wastes as fuel for habitat power sounds encouraging, but the fact remains that at the present time no feasible power production process using wastes for fuel is adaptable to undersea facilities. Rejection of solid wastes into the surrounding water is not recommended, particularly with respect to the scientific and marine study purposes of the facility.

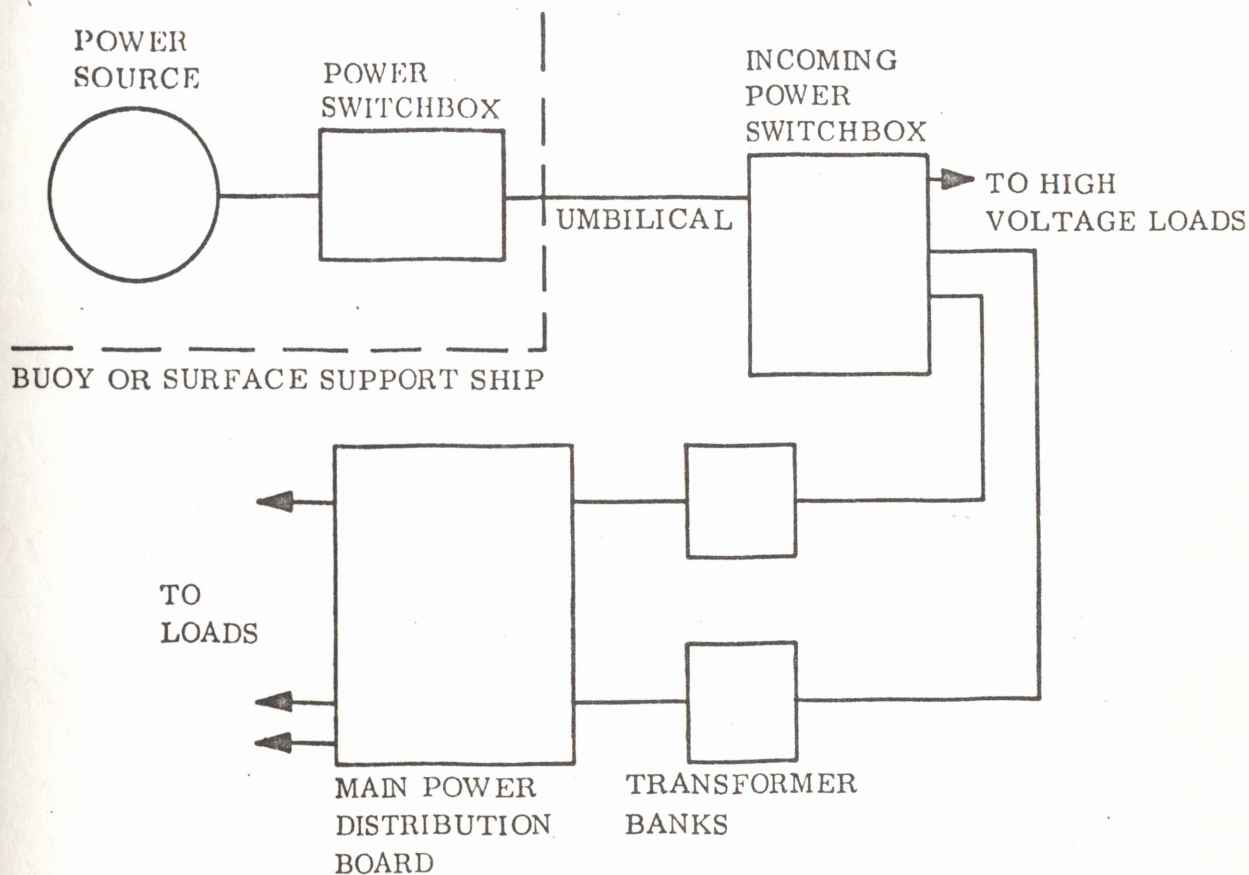
Water effluent from showers and laundry has, in previous habitats, usually been filtered to remove the most harmful contaminants and subsequently rejected into the surrounding water. This effluent is perhaps the best candidate for reclamation however, and if not feasibly purified for human consumption, could at least be processed sufficiently potable for bathing and laundry purposes.

Human wastes have in previous habitats been passed through a maceration-disinfection system, eventually discharged as pathologically safe material into the sea. But once again, the purposes of this facility I believe dictate the discharging of no such material, and thus imply the reclamation of water and the storage of solid material --- perhaps in conjunction with the storage of garbage and packaging wastes.

Chemical and similar wastes from laboratory work are perhaps the most dangerous of wastes produced in the facility, and it is imperative that they not only be kept from the sea and its inhabitants but also kept from contaminating humans, scientific specimens, or equipment within the habitat.

Electrical Distribution

A habitat electrical power distribution system must provide two functions. The first is to control power to the assigned loads at the correct voltage levels; the second, but no less important function, is to protect the load and the habitat personnel. The following block diagram defines the major components of a typical habitat electrical power distribution system.



Switches must be provided within the habitat, and also at any support vessel, to cut off all power in emergency situations.

The basic utilization voltages used by U. S. habitats are 208/120, 220 and 440 volts, 60 cycle, single or three/phase. These are primarily determined by the operational voltages of equipment used within the facility. If a voltage as high as 440 volts is to be utilized in the habitat, all equipment controlling and utilizing the voltage should be physically isolated from normal areas occupied by the crew.

The design of a habitat electrical power distribution system for the most part can make use of commercial products, but special consideration must be given to the following areas:

1. fire resistance
2. protection from moisture condensation
3. corrosion resistance
4. increased pressure
5. increased thermal conductivity in Heliox atmospheres
6. toxicity in an essentially closed atmosphere
7. increased chance of electrical shock due to ever-present hull ground

In the design of any habitat electrical system there is always a desire to limit instantaneous power draw --- the most obvious method of achieving this goal is to limit certain tasks, laundering for example, to off-peak hours. Another more sophisticated approach would involve the installation of an automatic switching network that would switch off loads in their order of importance to maintain the electrical power draw below a predetermined maximum level.

An automatic switching network also appears to be the most accepted solution for bringing emergency power on the line during

a power outage. Presently available emergency power sources usually take up considerable space, require charging, and in some cases present an operational safety threat to the crew. Therefore, an effort should be made to minimize the power requirements for minimal emergency operation.

NOTES ON LAYOUT

NO.	ITEM	QUANTITY	REMARKS
1	Storage	1	Emergency power source
2	Storage	1	Emergency power source
3	Storage	1	Emergency power source
4	Storage	1	Emergency power source
5	Storage	1	Emergency power source
6	Storage	1	Emergency power source
7	Storage	1	Emergency power source
8	Storage	1	Emergency power source
9	Storage	1	Emergency power source
10	Storage	1	Emergency power source
11	Storage	1	Emergency power source
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Lighting

High intensity, maintenance-free lights with short lifetime for underwater applications have been state of the art for years, but recent requirements of longer mission capability have added long lifetime to the specifications. Experience indicates that quartz-iodine or other halide lights have longest life (300 to 600 hrs.) if operated at optimum conditions. For internal lighting of the habitat, standard incandescent bulbs can only be used to 200 ft. --- thereafter, stronger bulbs must be developed to withstand the increased pressures.

Quartz-iodine lights show promise for deep applications because of their strong glass envelope, and they also have a light spectrum compatible with undersea photography. Florescent lights sealed in pyrex cylinders have been used successfully for interior and exterior lighting.

The following diagram indicates desirable illumination levels for various areas or tasks within the facility:

FOOTCANDLE LEVELS BASED ON I.E.S. RECOMMENDATIONS

5 FC	10 FC	20 FC	30 FC	50 FC	70 FC	100 FC	150 FC	200 FC	500 FC
Parking	Storage	Lobbies	Lavatories	Classrooms	Proof-Reading	Drafting	Fine Drafting	Fine Drafting	Color Identifications
TV viewing	Rough Stock	Auditorium	Corridors	Stores	General Assembly	General Assembly	Fine Assembly	Extra Fine Assembly	Minor Surgery
Construction	Receiving	Corridor	Conference Rooms	Reading Rooms	Testing	Testing	Testing	Testing	Special Inspection
		Stairway	Casual Desk Work	Testing	Inspection	Inspection	Inspection	Severe Office Tasks	Testing
		Dining	Cafeterias	Inspection		Counter Displays	Display Lighting		Very Severe and Prolonged Visual Tasks
				Rough Assembly			Severe and Prolonged Seeing Tasks		
							Medium Severe Office Tasks		

Various aspects of the lighting system can contribute to the livability and function of the facility --- for example, the use of different colors for definition, variety, or mood indication. Illumination levels should also be as user manipulative as possible, particularly in leisure and scientific work areas.

Decompression

Any return to the surface from a saturation dive requires decompression. The extent of the decompression phase is dependent upon the saturation depth and breathing gases employed at the saturation depth. This is clearly illustrated by two examples: one, the 20½ hour decompression from a nitrogen-oxygen saturation at 50 feet (Tektite II), and the other, an 8 day decompression used by the Navy from helium-oxygen saturation at 1,000 feet.

There are basically two ways to handle decompression at the conclusion of a mission: 1. aquanauts are decompressed within the habitat itself or 2. aquanauts are transferred via some pressure vessel to remote decompression facilities.

The first has several advantages over the second --- it facilitates completely independent operation; it provides immediate recompression for a diver accidentally breaking the time/depth limit; and it lessens the amount of equipment needed and the number of transfers required for personnel decompression. This capability within the habitat itself will increase the complexity of the facility, but this increase becomes insignificant when compared with the advantages, particularly with respect to safety.

Decompression is a complex process which involves the use of predetermined schedules to insure safe expulsion of inert gases. The following example is the decompression schedule used for Tektite II.

MODIFIED REGULAR DECOMPRESSION SCHEDULE USED IN TEK TITE II

DEPTH (feet of seawater)	TIME SPENT AT STOP (Minutes)	CUMULATIVE DECOMPRESSION TIME (Minutes)	BREATHING ATMOSPHERE
42			
"ascent"	12	12	Air
30	120	132	Air
30	30	162	Oxygen
"ascent"	5	167	Oxygen
25	200	367	Air
25	30	397	Oxygen
"ascent"	5	402	Oxygen
20	170	572	Air
20	30	602	Oxygen
"ascent"	5	607	Oxygen
15	20	627	Air
15	30	657	Oxygen
15	20	677	Air
15	30	707	Oxygen
15	20	727	Air
15	30	757	Oxygen
15	20	777	Air
15	30	807	Oxygen
"ascent"	5	812	Oxygen
10	60	872	Air
10	30	902	Oxygen
10	20	922	Air
10	30	952	Oxygen
10	20	972	Air
10	40	1012	Oxygen
"ascent"	5	1017	Oxygen
5	200	1217	Air
"ascent"	5	1222	Air
Surface			

Total decompression time: 1222 minutes, or 20 hr. and 22 min.

Total 100% oxygen inhalation: 335 Minutes, or 5 hr. and 35 min.

In addition to the normal decompression schedule, it is necessary to also consider emergency schedules, especially for relatively shallow habitats. The most common emergency in shallow habitats is accidental surfacing. In the case of Tektite (42 ft saturation depth) it was determined that recompression within 15 minutes after such an incident would prevent fatality. In the case of the Minitat (100 ft. saturation depth) this time was reduced to 3 minutes. It has become evident that as the saturation depth increases, the range of depth and time limit within which a diver can operate without decompression also increases, thus lessening the chances of a depth/time accident.

Decompression facilities increase in scale as the saturation depth increases, primarily as a result of the greater amount of time required. An eight day decompression schedule will require food, water, and a multitude of provisions and facilities for comfortable, healthy livelihood throughout the occupant's stay. These requirements are substantially greater than those for an eight hour decompression.

Movement

There are two basic modes of movement used today underwater, propellers and water jets.

Propellers have been the basic method of propulsion both underwater and on the surface of the water for decades. Modern ships and submarines both use propellers driven by machinery using a variety of power sources --- the propeller itself differs little among vehicles and little from its predecessors. The widest range of variation is that of size --- from those used in small pleasure boats to larger varieties used for submarines and massive cargo vessels.

The hydrolic water jet is a relatively recent development employing the use of pumping mechanisms to draw in water and subsequently expel it under pressure in a controlled direction. Jacques-Yves Cousteau uses water jets to maneuver his diving Saucer DS-2, and hydrojets will also be used for maneuvering the Navy's Deep Submergence Rescue Vehicle, quite similiar to the way gas jets are used to maneuver space vehicles. Hydrojets as yet have not to my knowledge been applied as major propulsion for large vehicles.

Main propellers are normally located at the rear of a vehicle --- if more than one are used they may be spaced some distance apart to gain stability. Some type of rudder arrangement has usually been employed to control direction. On the research submarine Alvin a single propeller, swivel mounted, was used for propulsion and direction control. Auxiliary propellers in various locations may be used for maneuverability. On Cousteau's Diving Saucer two hydrojets are located on opposite sides of the vehicle, toward the front. These jets swivel to give a maximum of maneuverability.

The main concern with respect to vehicle shape as an effect upon movement is to reduce the amount of surface area perpendicular to the direction of movement. This is part of the reasoning behind the cigar shape of the military submarine. Many of the recent research submarines have become more blunt, partly because of their spherical chamber shape, but also because the demand for speed is much less --- many times speed would be detrimental to observation.

A mobile habitat should have some means of resting on the ocean floor in a stable, level position. Some past habitats have been set on previously leveled ground and/or used extensive anchoring systems requiring much preparation and installation time and labor. Both of these approaches require too much time and labor for efficient placement of an undersea facility. Perhaps a much more desirable approach is that of adjustable legs. Such supports have been used successfully, and enable the habitat to be emplaced levelly on very uneven terrain. Anchoring systems of some sort to resist waves and currents will probably always be required, but attention should be paid to their complexity and speed of placement/retraction.

Safety

The operation of an undersea laboratory, isolated in alien surroundings, necessitates an increase of substantial proportions in safety considerations over and above those commonly considered in surface facilities.

The following is a list of hazards associated with undersea facilities and their operation.

- LACK OF ENDURANCE OF PRIMARY UTILITIES
- FAILURE OF PRIMARY UTILITIES
- FAILURE OF UMBILICAL
- FAILURE OF SURFACE COMMUNICATIONS
- CONTAMINATED ATMOSPHERE
- FIRE
- FLOODING
- DIVER INCAPACITATED IN HABITAT
- DIVER INCAPACITATED IN WATER
- HAZARD REQUIRING EVACUATION
- INOPERATIVE PRIMARY DECOMPRESSION FACILITY
- ONE DIVER BENT
- ADVERSE WEATHER
- LOSS OF AIR WHILE DIVING
- ACCIDENTAL DIVER SURFACING
- EXCEEDING EXCURSION LIMITS
- DIVER LOST
- PREDATOR HAZARD
- FAILURE OF SWIMMER VEHICLE WHILE REMOTE
- ENTANGLEMENT OF DIVER EQUIPMENT WITH LINES, MOORINGS
- OBJECT DROPPED ON HABITAT OR DIVER
- VESSEL MOOR SHIFTING

One of the most serious accident possibilities is contamination of the habitat atmosphere. Emergency systems employed for such contamination consist primarily of BIBB (built in breathing) systems, SCUBA systems, and surface supplied gas mixtures. BIBB systems are supplied by bottle tanks containing a breathable premix for the depth of operation and are usually mounted on the exterior of the habitat. Supply lines are routed inside the habitat where a length of hose and demand regulator are available for personal use. SCUBA bottles are also used primarily when the contamination levels are such that the habitat gas is totally unbreathable and may be so for an extended period of time.

When the contamination levels are not critical but are increasing, the usual approach is to deploy contaminant collectors within the habitat and allow the natural movement of the atmosphere to expose the contaminants to the collectors. A second approach is to purge the habitat, or a portion, with bottle or surface supplied gas, thereby reducing the contaminant concentration.

Fire is another extremely dangerous hazard in an undersea facility. The combustibility of various materials is affected primarily by pressure and the oxygen percentage of the atmosphere. Extensive research and testing has been done, and is continuing, to provide designers with combustion rates of various materials under various conditions.

One of the major advantages of a rigid pressure chamber habitat over an inflatable habitat is its ability to operate as a decompression chamber itself. This would allow the entire facility (or perhaps a certain section) to surface, and keep itself at the saturation pressure of the occupants while waiting for rescue. Add to this the ability to naturally surface by means of positive bouyancy, and the capability of undertaking decompression independently, and the result is a superior escape mode

for leaving the bottom. Another escape consideration should be the inclusion of a topside hatch for mating with a DSRV (Deep Submergence Rescue Vehicle).

It has become standard practice to include in the design of underwater habitats secondary power sources, gas sources and sometimes water and food sources. For an independently operating facility, these secondary sources become even more important, because the time lag between disaster and rescue will undoubtedly be longer.

An emergency module is considered an extremely desirable part of any manned habitat regardless of size or mission orientation. This area must be capable of sustained isolation from the rest of the habitat, and provide an independent life support system. In a situation where a supporting surface vessel is not in attendance, and evacuation is required, the emergency module might function to decompress the occupants under an established schedule and serve as a refuge until surface support is available. After appropriate decompression and with surface ships overhead, the occupants may free dive to the surface through an egress provided in the emergency module. The egress also may serve as a habitat emergency exit. An emergency module capable of separation from the habitat and surfacing under its own power of bouyancy would be an even safer escape mechanism.

The emergency module may double during normal operations as a medical supply and treatment room, and if necessary, an isolation ward. The emergency room can also serve as the decompression chamber to handle situations wherein individuals working outside may exceed the narrow depth/time restriction prescribed. To handle transfer of supplies and personnel and evacuation of sick or injured individuals, the emergency room might have a mating and dry transfer provision for a Personnel Transfer Capsule.

Communication

Habitat Internal

Habitat internal communication and control is perhaps the most crucial to successful operation of the facility.

First let us consider monitoring and control of the life support system. A number of techniques and instruments are available for gas monitoring. The following table illustrates the most applicable of these techniques and what they will successfully monitor.

MONITORING INSTRUMENTATION

TECHNIQUE	O ₂	N ₂	He	H ₂ O	CO ₂	CO	TRACE
Gas Chromatography	x	x	x	x	x	x	x
Infra-Red, Non-dispersive				x	x	x	
Infra-Red, Dispersive					x	x	x
Mass Spectrometry	x	x	x	x	x		x
Para-Magnetic	x						
Electro-chemical	x				x		
Chemical	x				x	x	x

The control of various gases is a relatively simple instrumental step from monitoring, since undersea habitats of significant depth are basically closed systems. The apparatus for monitoring and controlling water supply systems, electrical systems, waste systems, etc. will vary little from those methods employed in surface applications.

Man communicates through his senses --- an investigation of each sense and its application to habitat communication is therefore advisable.

Vision is the most sophisticated sense man possesses, and the number of different variables it enables him to decipher reflects this sophistication. Vision is also the sense most people rely on for most of their information. The use of differing colors, differing shades and tints of color, differing patterns, differing intensities, and differing illumination levels are all variables which can communicate something to someone through their visual organs.

Man depends upon hearing second only to vision. Besides the use of sound within the habitat as warning, it can also be used to instigate various moods, to camouflage mechanical and other undesirable noises, and as an entertainment media. It must be remembered that helium affects the production of the human voice --- however it does not affect one's hearing ability, the transmission of sound, or the mechanical production of sound.

Tactile sensing is usually considered principally in terms of heat and cold. Aside from a standpoint of comfort, temperature differences should also be investigated as warnings or as means of spacial separation or spatial function indicators. When designing a closed, isolated living-working facility such as an undersea habitat, it is imperative that the designer be consciously aware of the psychological space parameters of the occupants. Helium again poses some problems ---

it conducts heat approximately twelve times as fast as air.

Texture constitutes a fertile field of investigation for use as warning, direction, differentiation and other instructional purposes. It also provides a major variable element for creating interest and diversity within the habitat.

Odors, provided they are quickly dispersed and easily removed, could also possibly be used to communicate various special messages to the occupants. Messages such as burning or cooking odors will be present within the habitat just as they are in surface spaces.

A very important consideration when involved with communication within an undersea habitat is the human comprehension of communication devices --- from gas monitors to simple directions to emergency instructions. It should be realized that the speed and accuracy of comprehension of graphic symbols has generally been shown superior to that of written messages --- this of course is relevant to the quality of design for either one. The likelihood of scientists of different language familiarity using this facility is also rather high --- graphic symbols can more successfully bridge these language differences..

The placement and prominence of communication mechanisms is also very important --- caution should be taken to lesson opportunities for messages to be covered or hidden by changes in furniture or equipment placement.

Past habitats have demonstrated the need for a central control area where the status of all habitat systems can be monitored and from which all habitat systems can be controlled. This area is not to preclude the installation of monitoring or control devices where advisable in other parts of the facility. It is important for general

safety reasons to provide at least mechanical
audio links --- and possibly vidio --- among
all major use areas of the facility.

Habitat to Swimmer

Equipment used for this link would either be based on a hard-wire connection between the swimmer and habitat, or the several acoustic systems listed in the following table.

SYSTEM	MANUFACTURER	COMMENT
Diver Communications System	Aquasonics Engineering Model 811	Acoustic Carrier 8 KHz, Range 100 Yds., 4.8 pounds, 600 ft. depth (11 x 4 x 4)
Yack-Yack, Raytheon	Y ² Co., Los Angeles	
Divercom	Electrodynamics Division N. Hollywood	Acoustic Carrier 8 KHz Range 100 Yds., 5 pounds 1000 Ft. Depth, (7 x 5 x 2)
Watercom	Same	Direct Acoustical System Range 50-100 ft., 5 pounds, Depth 300 ft., Broadcast or 2 Way (4 x 4 x 13)
Broadcast System	Marine Resources, Inc. Fern Park, Florida	Direct Acoustic System No Diver Equipment
Wireless Underwater Communication System	Sub Comm Systems N. VanCouver, B. C. Model 130D	Acoustic Carrier (30 KHz) Range 100 Yds., 4-1/2 pounds

These same mechanisms can be used for emergency systems, but they would only be successful for relatively short reaches to surface vessels. Much research is going on at the present time concerning the development of more dependable, longer range acoustic systems for underwater application.

Habitat to Shore

Radio, telemetry, and television cannot be transmitted any appreciable distance through water. These types of communication are imperative to the operation of an undersea facility, and thus will require a deployable, cable linked, surface buoy to transmit such signals to shore and to receive replies from shore.

Commercial radio and more recently commercial television have been made available to aquanaut scientists for entertainment purposes. Even though lousy reception impaired the validity of studies conducted concerning their use, it is generally conceded that these links are valuable for crew comfort and the relieving of isolation stresses.

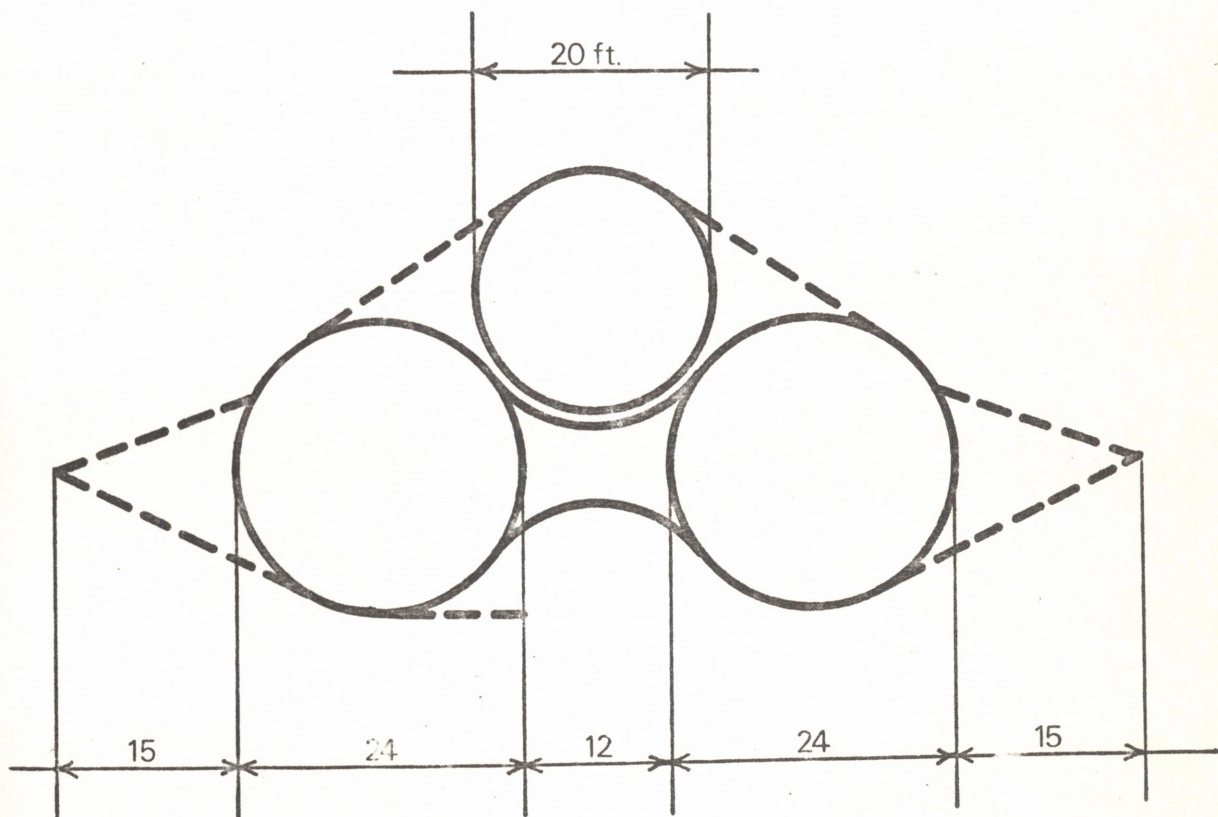
Radio and telemetry links have been used considerably for habitat to surface or habitat to shore communications. Two-way closed circuit television has only recently been tried in the second Tektite series however, and studies of use and value were made during those missions. Conceding that the quantity of observations were small, it has been generally agreed that this link was responsible for much smoother and better communication for work and operational use. Another very important observation was that concerning personal use by the aquanauts --- this video link was very popular, and appeared to help considerably in easing social tensions and isolation stress.

conceptual results

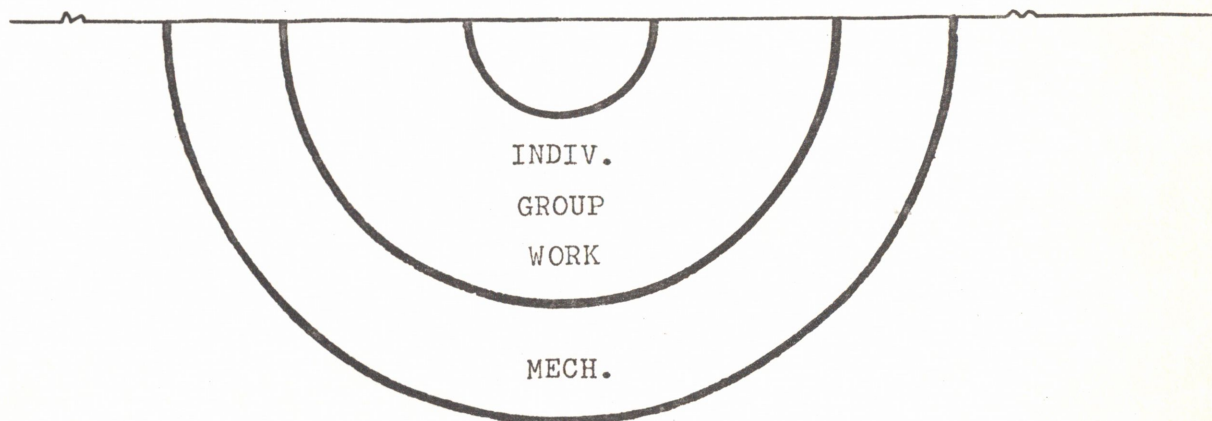
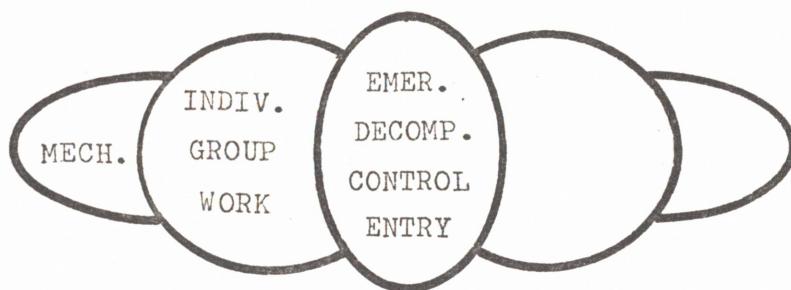
The following size estimates were used in the development of this concept (they must be accepted as extremely rough approximations):

sleep/individual-----	1200 sq. ft.
group-----	500
work-----	500
control-----	120
lavatory-----	200
food preparation-----	120
life support storage-----	200
work storage-----	200
mechanical-----	2000+
emergency/decompression-----	500
entry/exit-----	200
auxiliary vehicle-----	200

The approximate resultant dimensions of the study are:



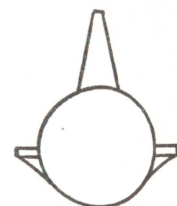
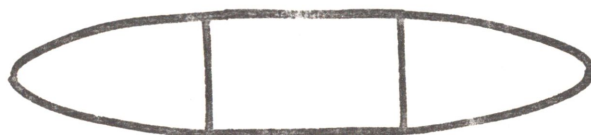
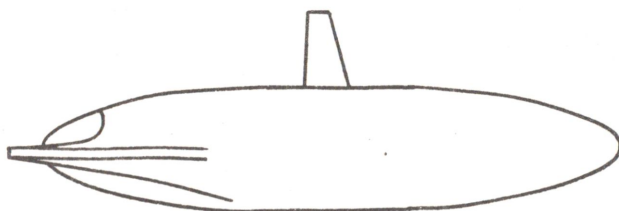
The first ideas around which this conceptual study was formed were the use of a disk shape coincidental with varying degrees of safety.



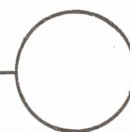
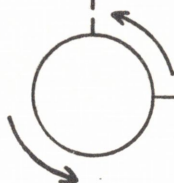
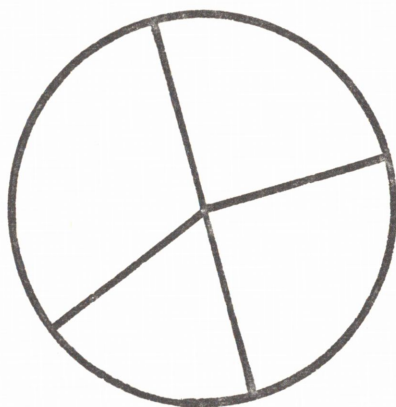
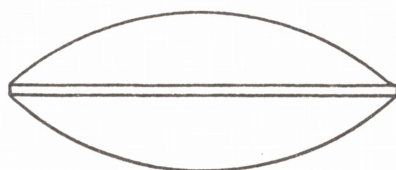
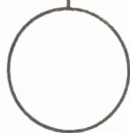
The disk shape was chosen as a more easily functional and efficient use of available space. It would enable a more consolidated, multi-directional use of the habitat enclosed area. As a disk, the facility would also have less resistance to movement than a sphere or blunt ended cylinder. Concurrently, it could gain improved maneuverability and possible improved stability --- both paramount considerations for undersea research laboratories.

Safety considerations were based upon a progression of relative safety from the exterior to the interior. Such things as the emergency escape module and decompression facility, the major control area, and the entry/exit area would occupy the central core. Surrounding this would be the major living/working area. Around the perimeter, the menagerie of mechanical equipment required to operate the facility would be placed. Much of this equipment may not need to be within the pressure hull, or may orient its function outward, and thus could be covered with a shell, shaped to aid the hydrodynamic properties of the whole. This concept allows those apparatus most likely to explode, burn, or dangerously malfunction to be placed at the most remote areas of the facility. At the same time, access for mechanically functional connections is provided to every space. Another safety-plus for a disk shape is that in a case where one compartment must be sealed off for one reason or another, access is still possible to all other areas --- in a conventional submarine shape or similar configuration a closed area in the center may prevent connection between the two end areas.

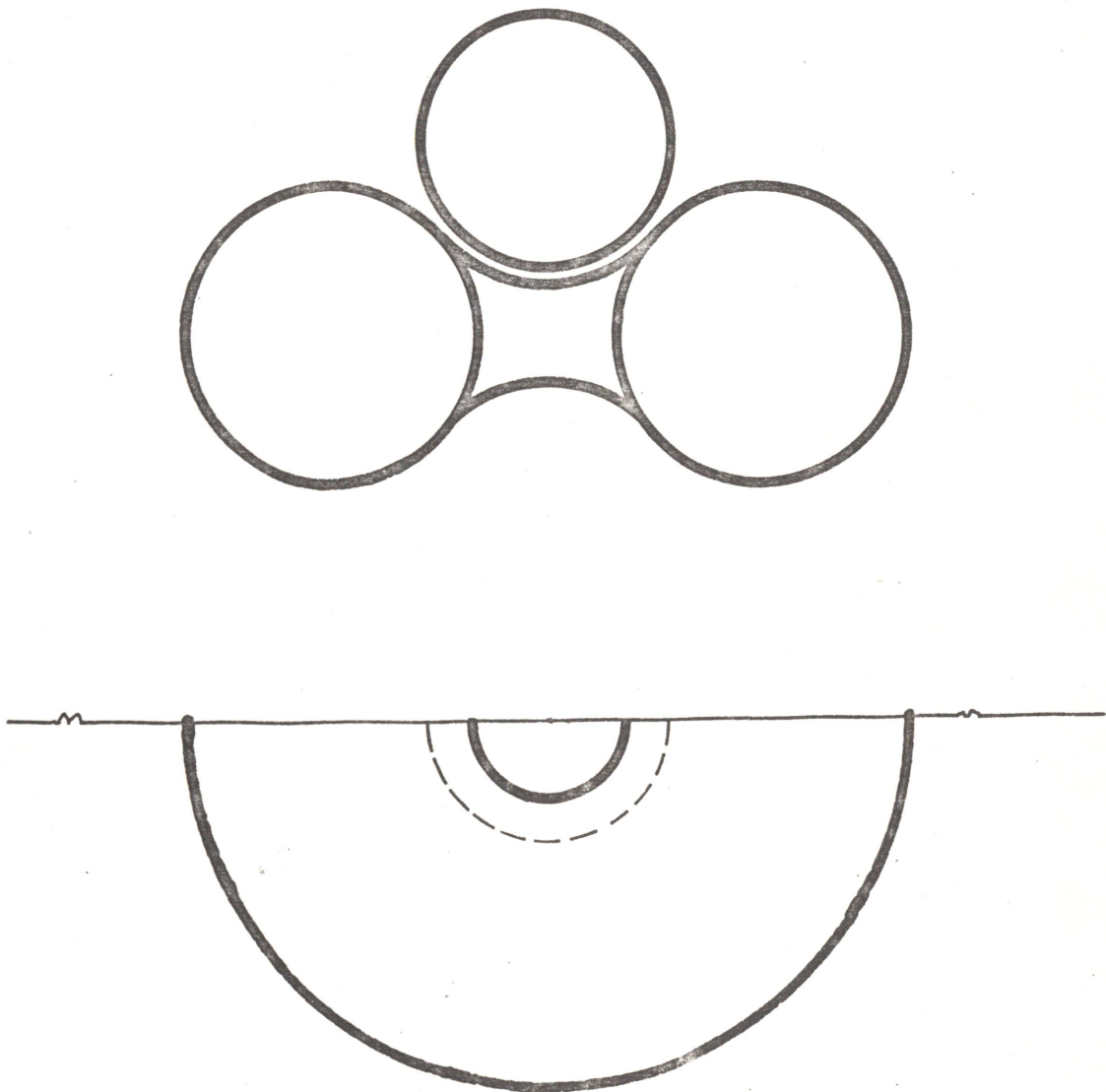
Conventional submarine shape



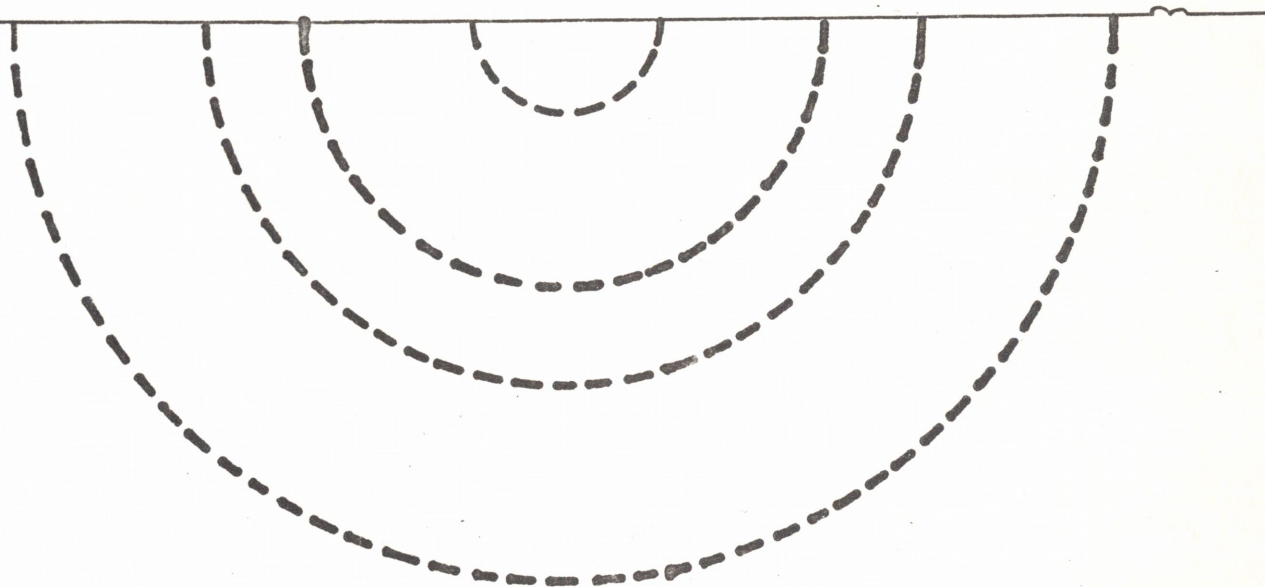
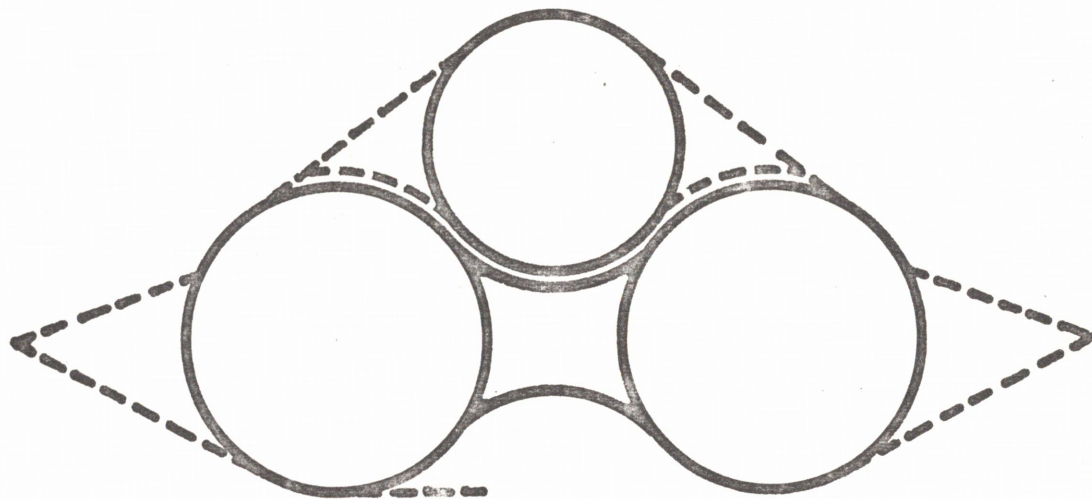
Disk shape



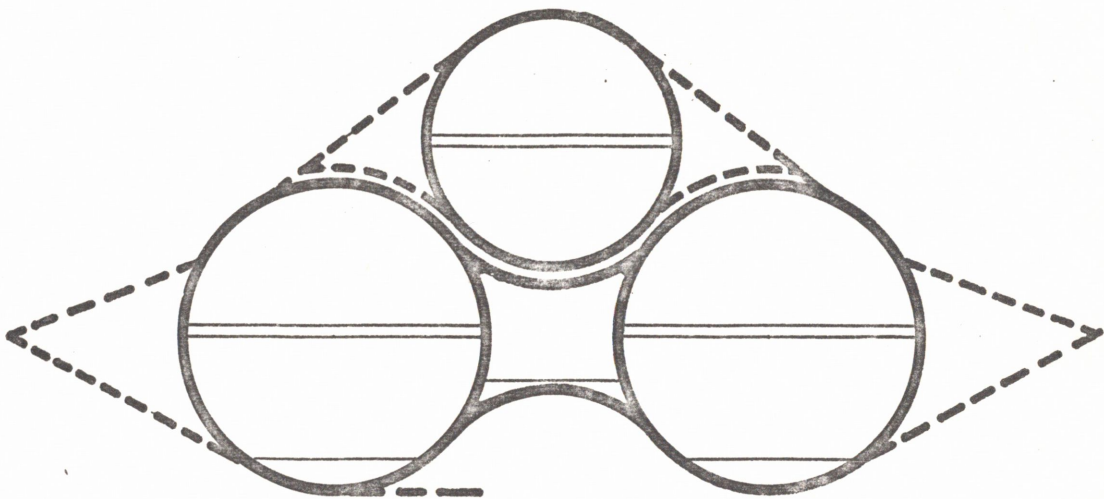
This concept gradually evolved into the use of a torus and companion sphere for pressure hulls. The torus is a sufficiently strong shape for the depth to which this facility would descend (1,000 ft.). The sphere would be used for the emergency module, increasing its capacity to withstand abnormal depths. Normally resting attached above the center void of the torus, this spherical emergency module would detach itself and rise to the surface for situations requiring evacuation of the habitat. By grafting two membranes shaped as a portion of a sphere over the void of the torus, a continuation of usable space across the torus is gained, with structural integrity still intact.



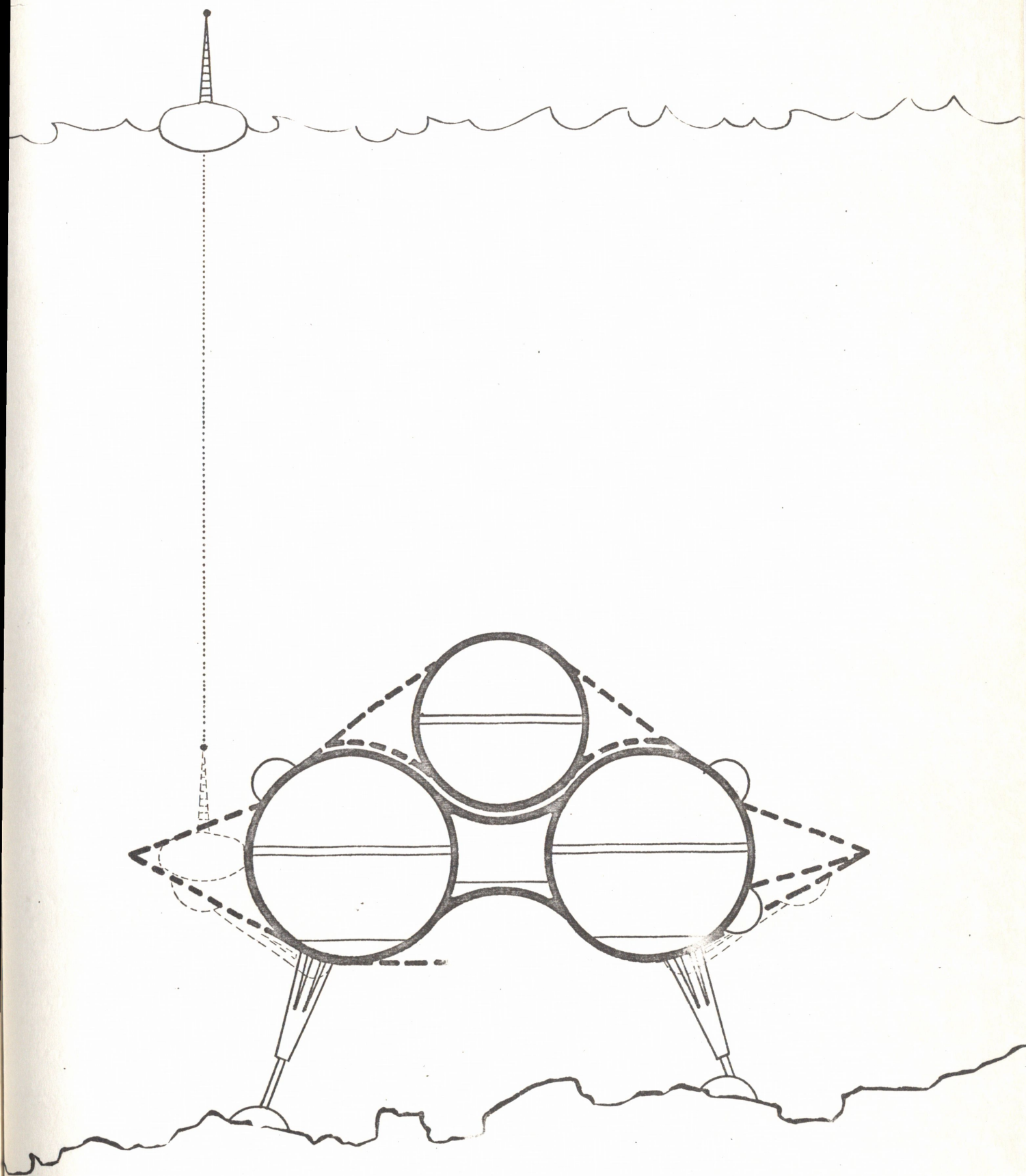
The addition of mechanical perimeter areas to both the torus and the attached sphere provide a shape suitable for underwater travel. By releasing the pressurized atmosphere of the interior into the remaining void in the lower portion of the center of the torus, an entry/exit area can be gained without supplementary structure or significant alteration of the basic pressure hull --- a back porch, so to speak. A portion of this open water area may be covered by a loading and working platform.



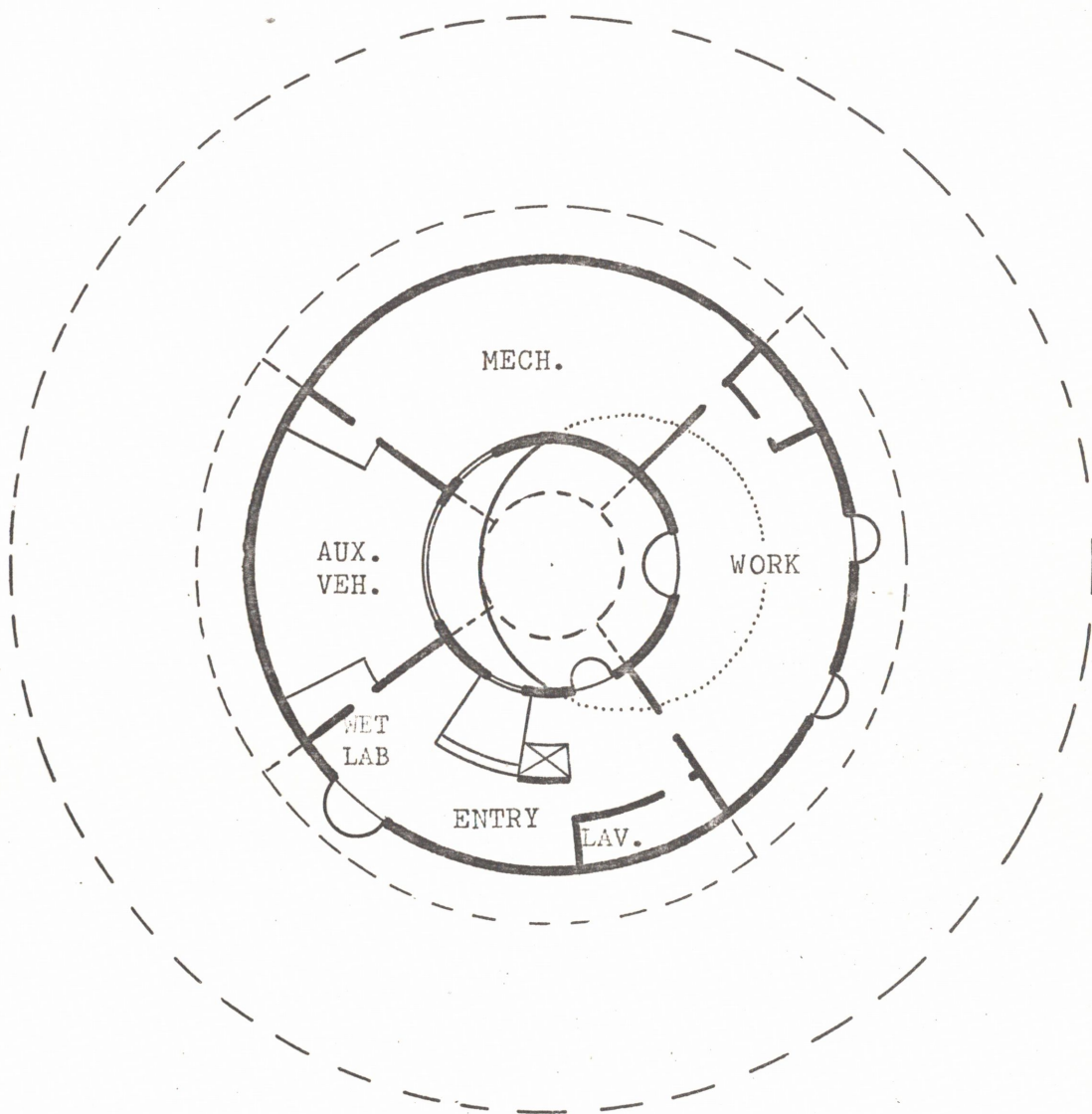
The interior space resulting from this configuration is best utilized in a two story arrangement --- the lower for working and the upper for living. The central control area, being offset one-half story from the rest of the spaces, will have visual contact with most of the area on both levels. The spherical emergency escape module may or may not work better as two levels --- this remains open to further study.



The laboratory rests on adjustable legs, thus enabling it to set levelly on uneven terrain with minimal ground manipulation. These legs would retract into the mechanical perimeter area during transit, not penetrating the pressure hull. A deployable surface buoy for communication and possible power provisions also would be released from the mechanical shell. The presence of hemispherical viewports is dependent upon whether metal or some form of transparent glass/plastic is used for the pressure hull.

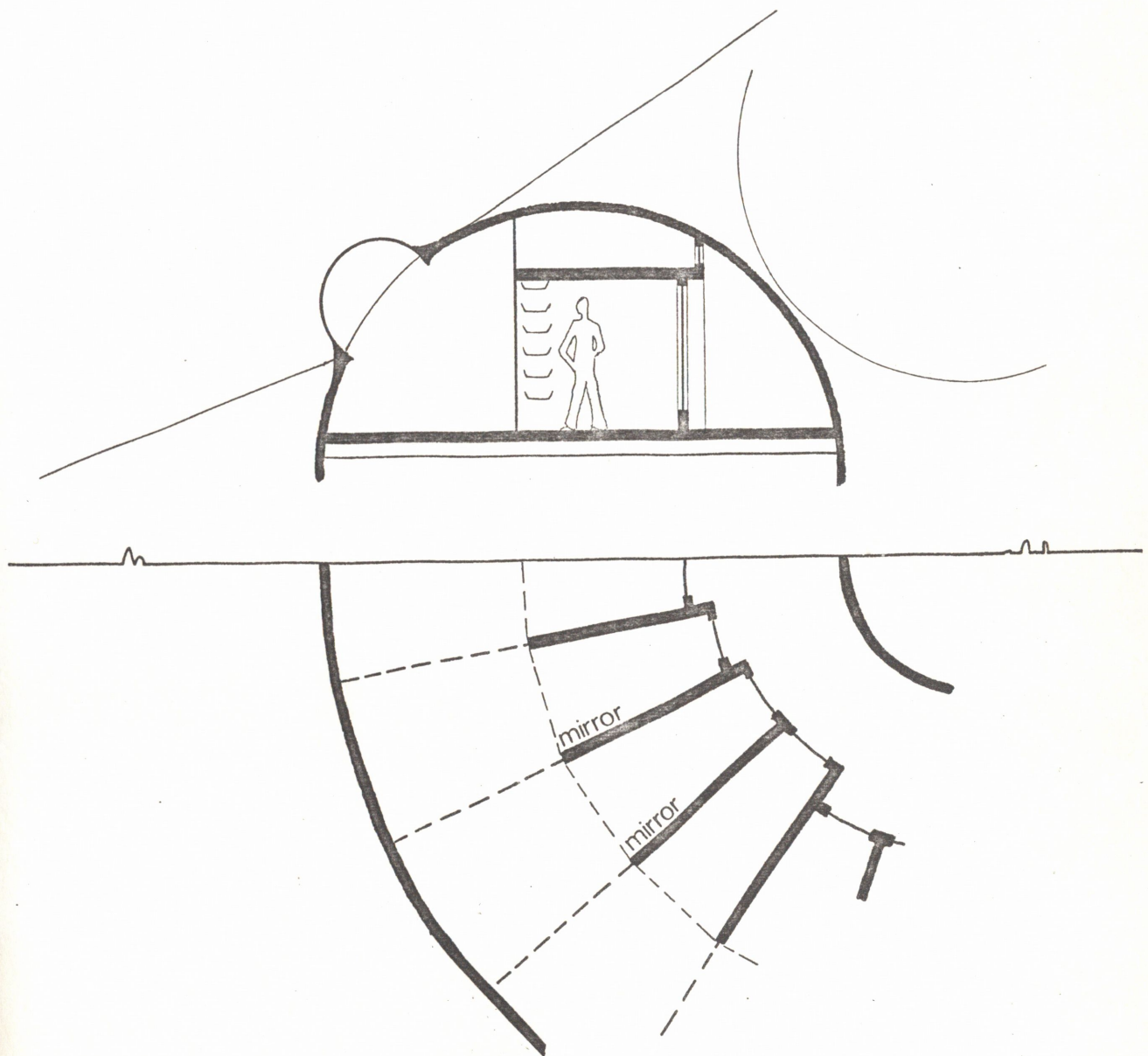


The lower level of the facility is functionally arranged as shown in the following diagram. Space has been provided for the storage of an auxiliary vehicle --- something most likely to accompany the laboratory when undertaking scientific exploration. The entry portion includes a wet lab, lavatory area, suit and scuba storage area, and lift to upper levels. Directly off the entry, the work area consists basically of an open free space, capable of changing easily to satisfy different project requirements. Fixed elements would occur at both wall surfaces. A mechanical section is provided for that equipment requiring location within the pressure hull.

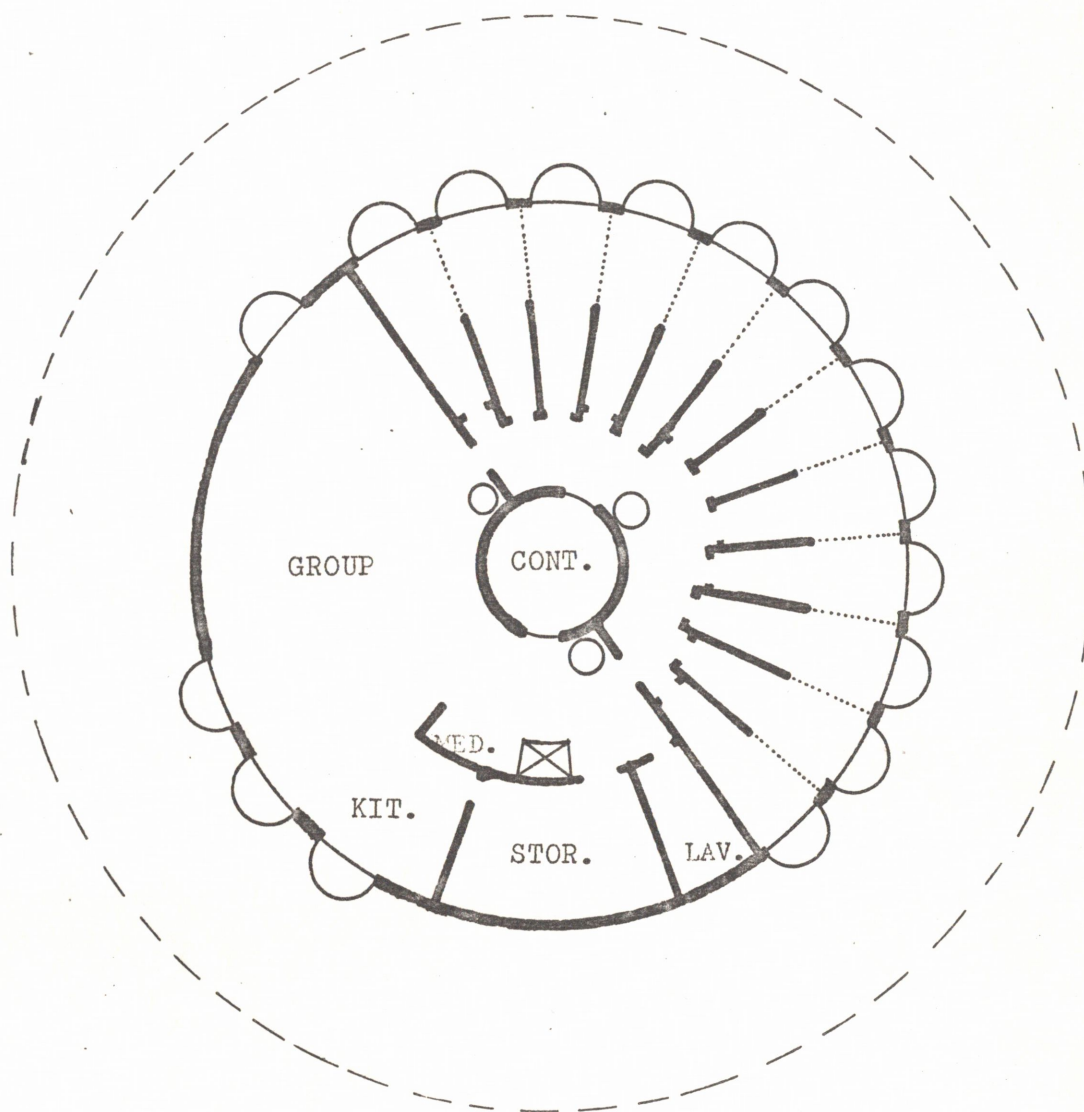


The facility's upper level is devoted to living quarters. Individual compartments are provided for each occupant; these compartments can be joined by retracting wall sections, thus obtaining various different room sizes for varying individual or group preferences.

The only fixed elements within these compartments are floor surfaces, one mirrored wall, and a second half-story balcony. Wall surface treatment, furniture configuration, and spatial usage are user manipulative.



Storage and medical areas are provided immediately adjacent to the lift. The group activities portion imitates the flexibility of the work area --- able to accomodate differing activities at different times. Fixed elements would similarly occupy the wall space.



credits

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National Wildlife
Newsweek
The New Yorker
Popular Science
Progressive Architecture
Readers Digest
Science Digest
Science News
Sea Frontiers

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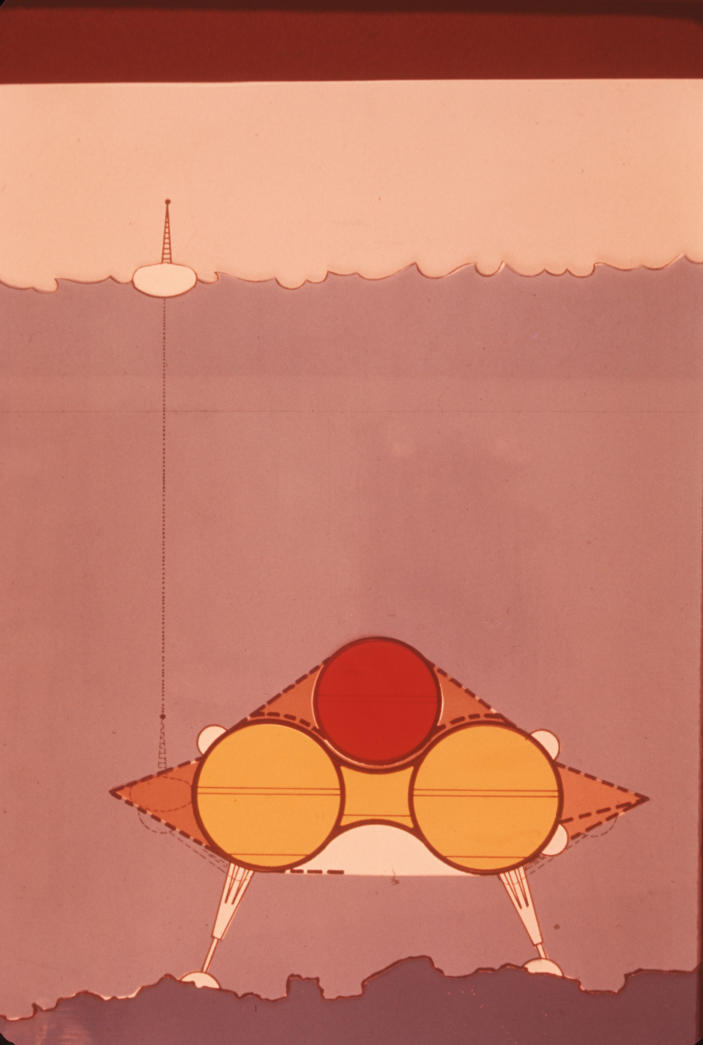
presentation

The final presentation for this project to the thesis committee and all other interested persons was in the form of 180 slides, organized in the following manner: orientation, conceptual diagrams, pictures from individual compartment models, major area perspectives, and conclusion. The following two pages contain first, a few excerpts from the final presentation slides, and second, a slide review of development work.

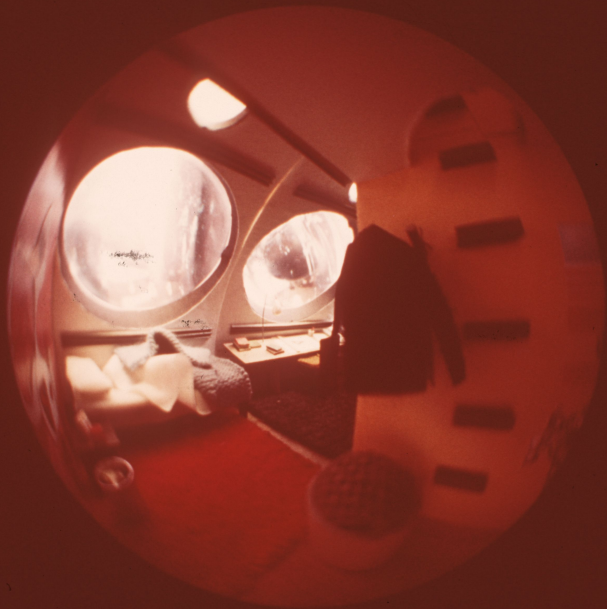
This final document presented to the Department
of Architecture, Montana State University, to
fulfill requirements for architecture thesis.

June 6, 1973

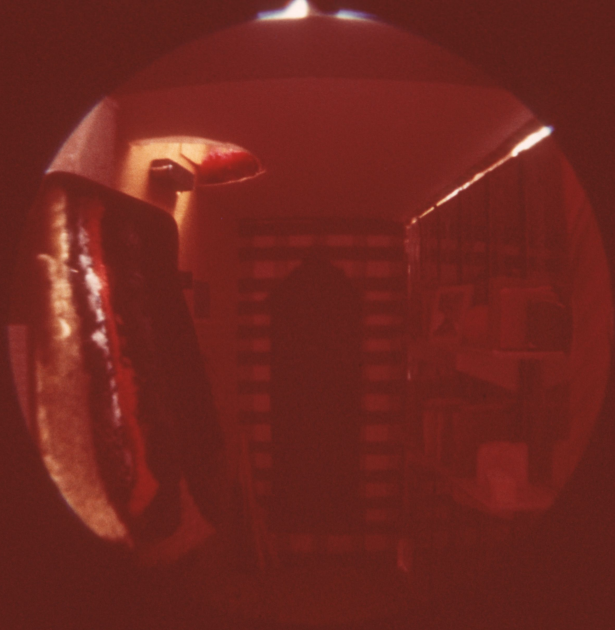
Larry J. Rafferty











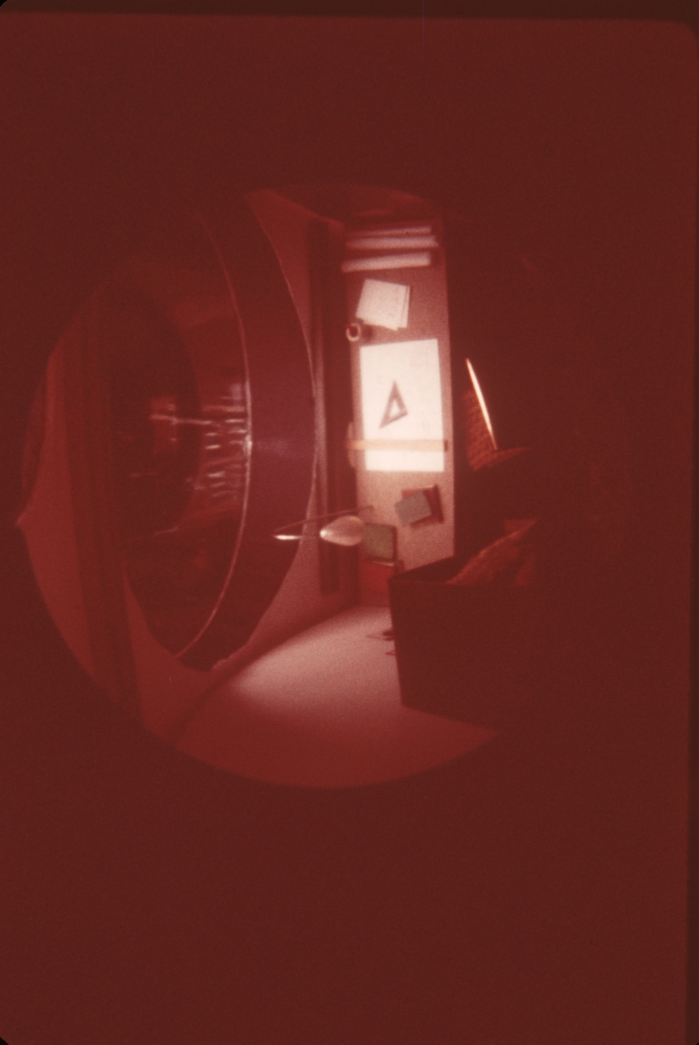










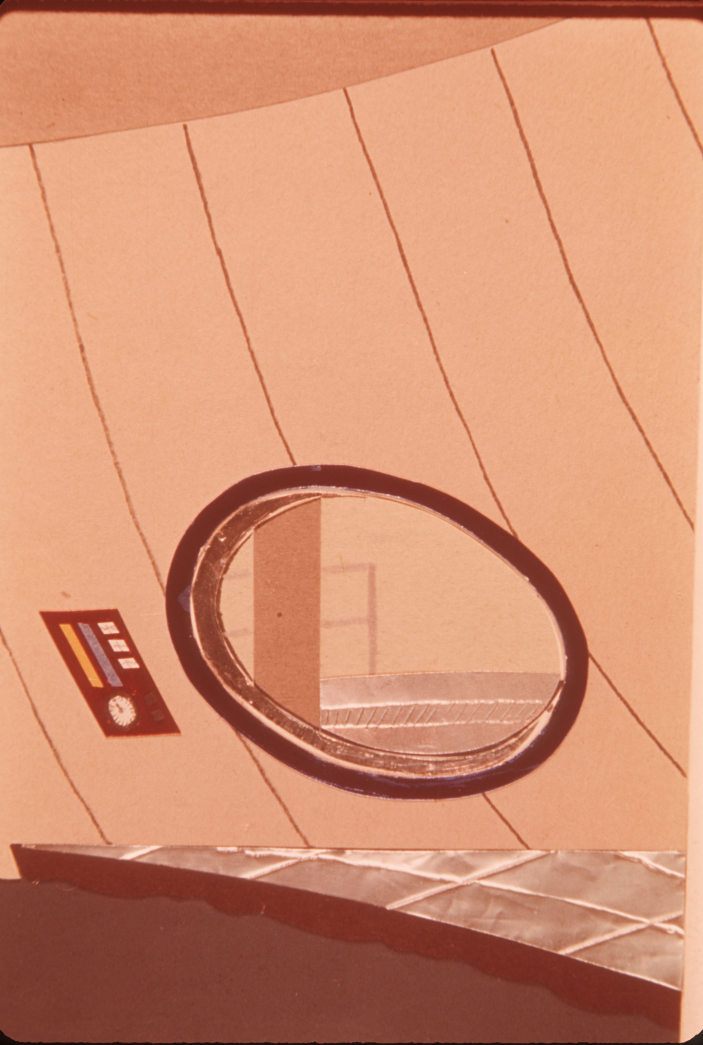


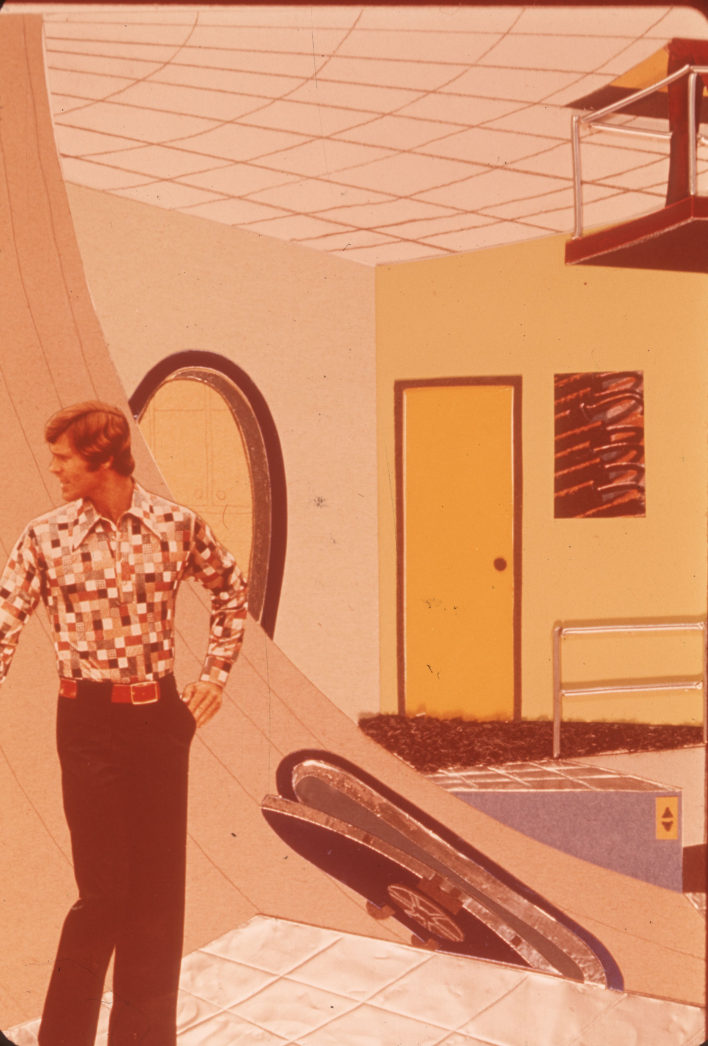




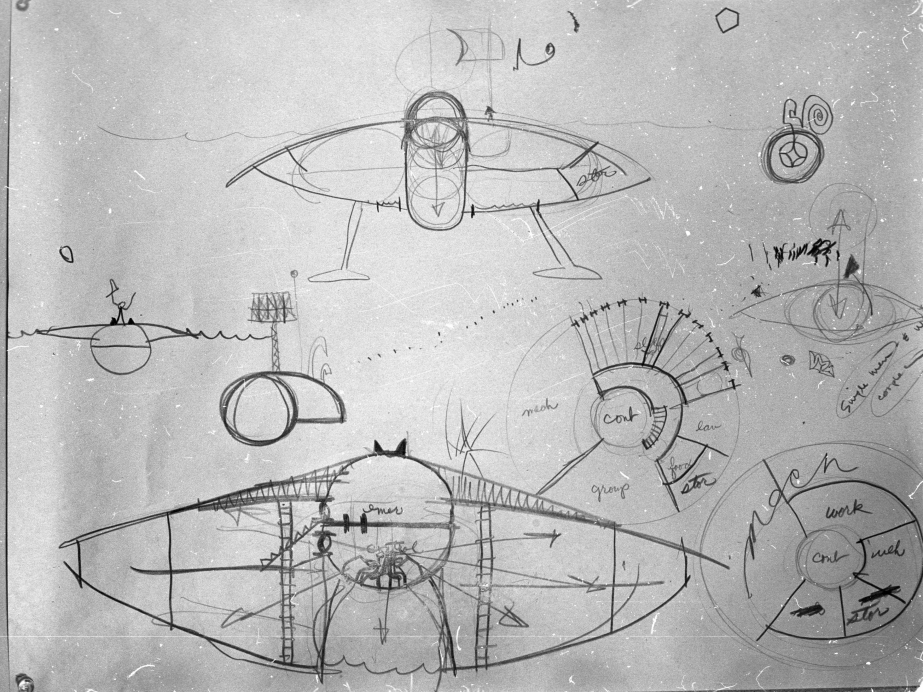


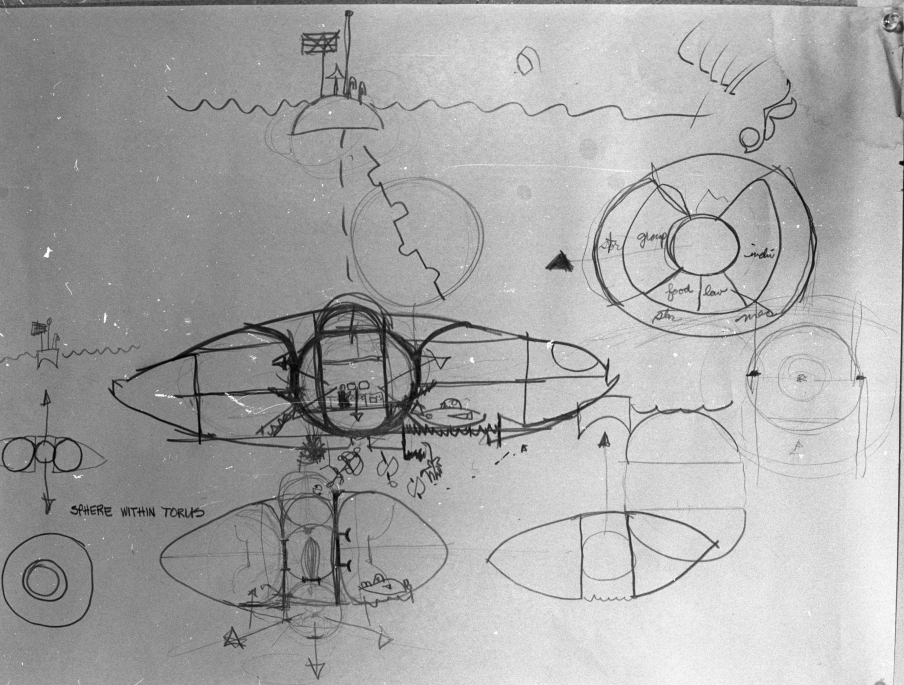


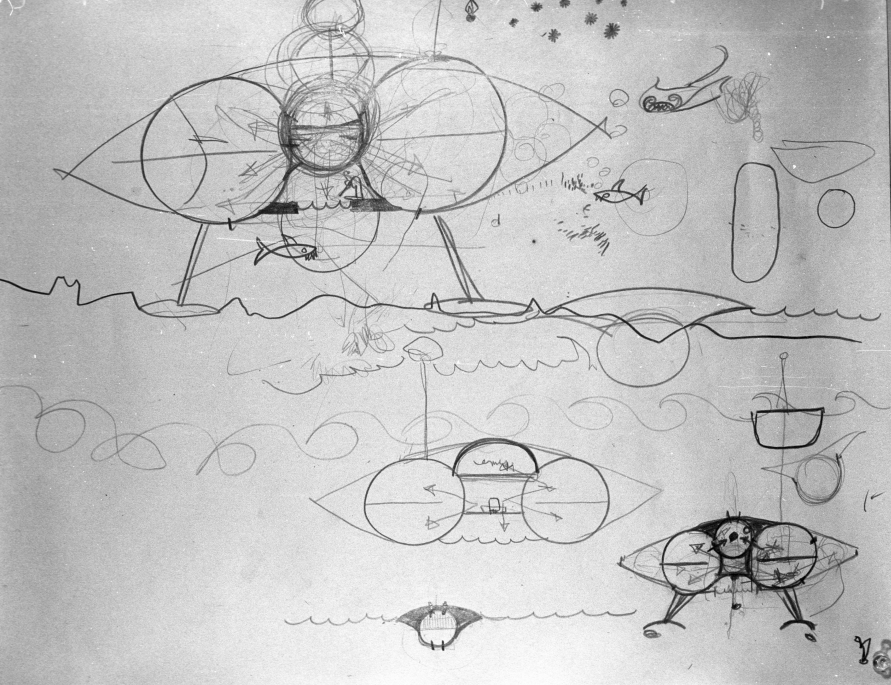


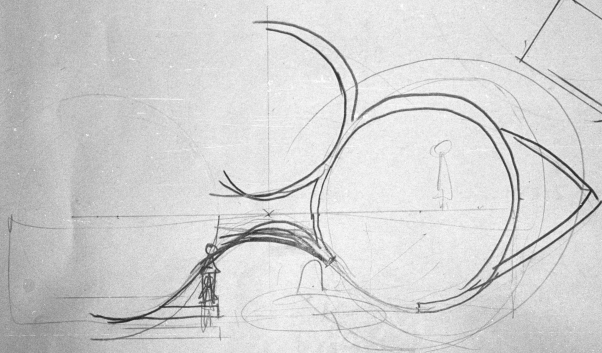


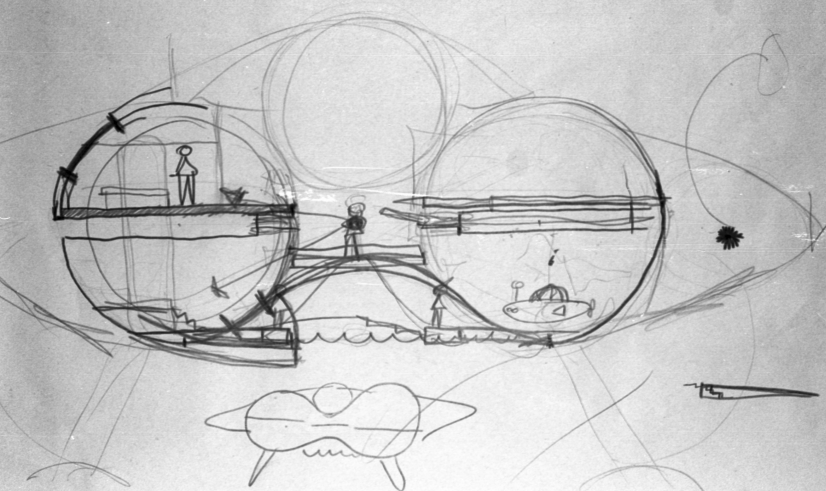


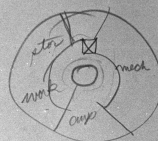
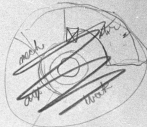
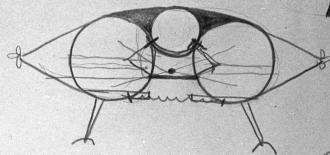
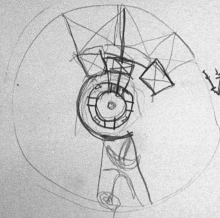
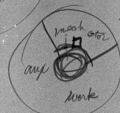
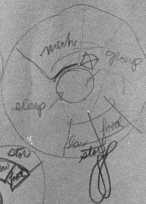
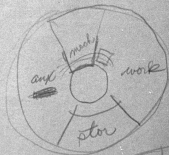
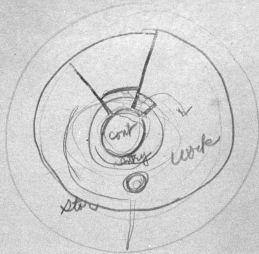
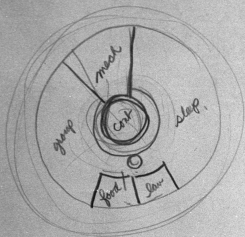


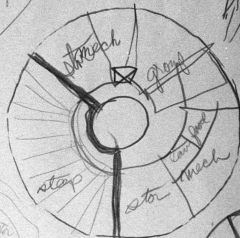
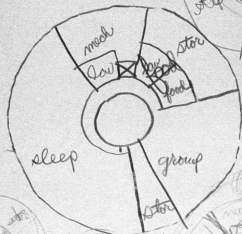
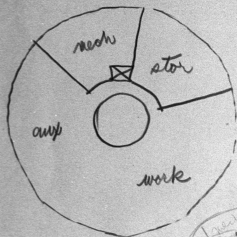
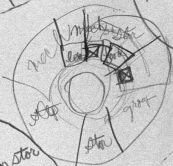
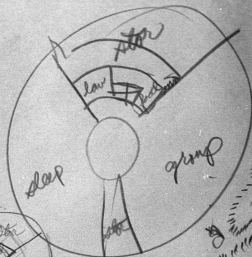
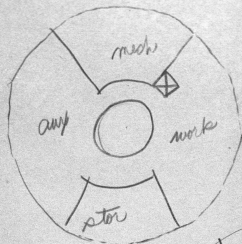
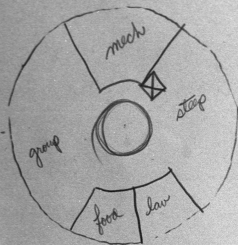


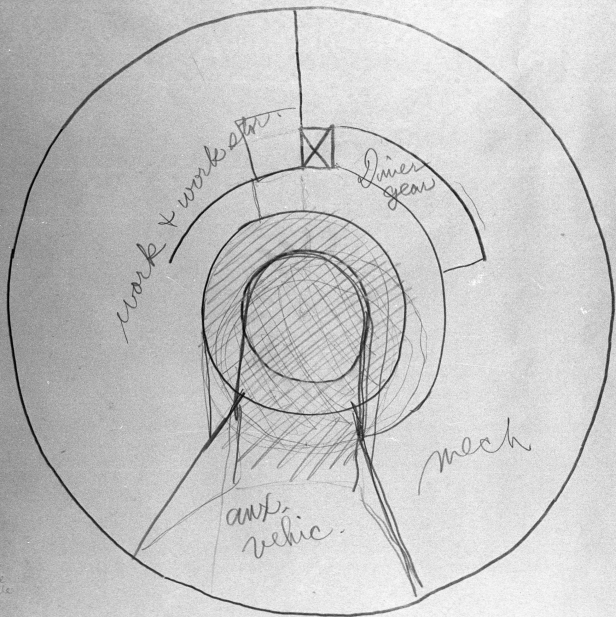




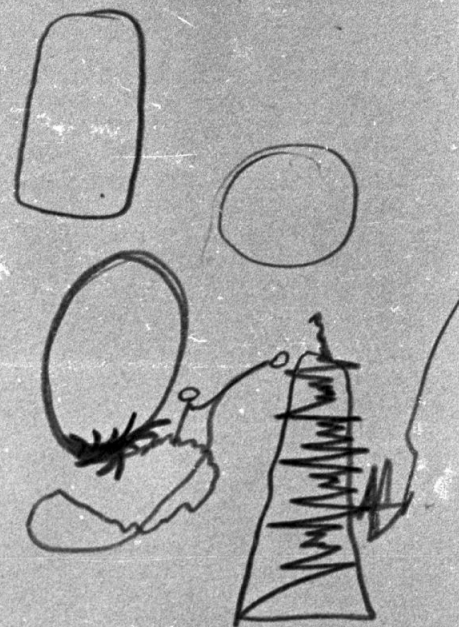
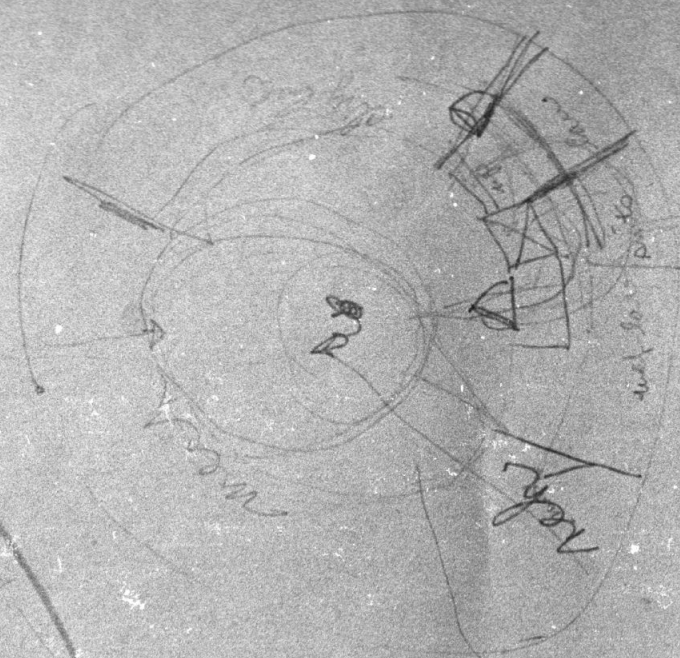
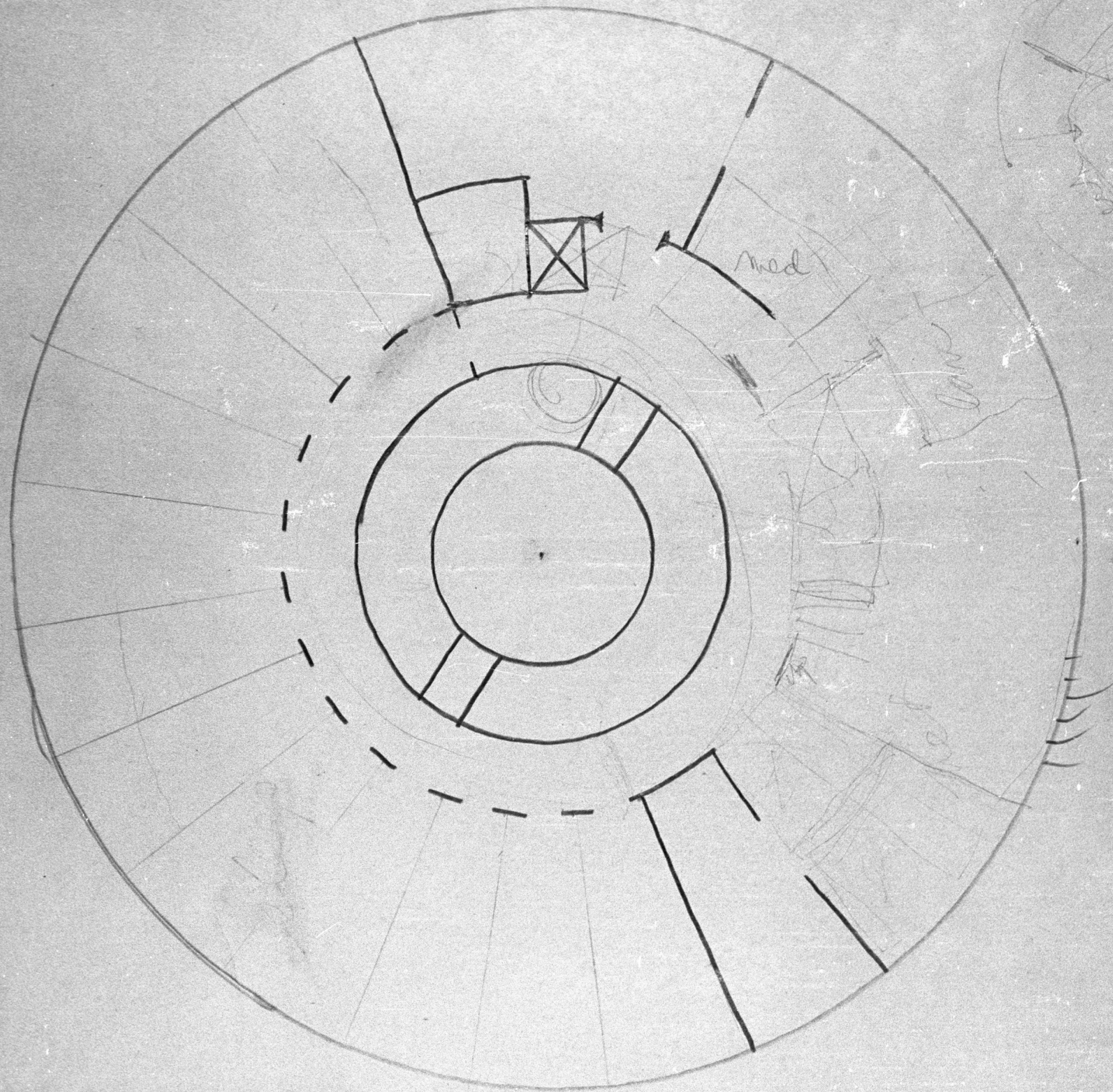


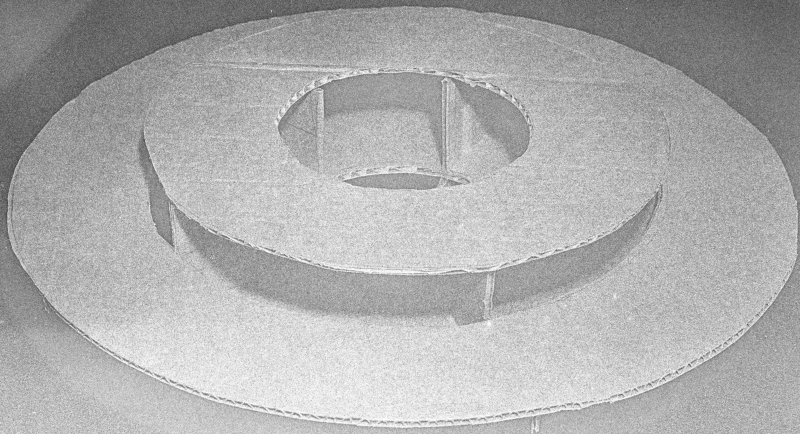


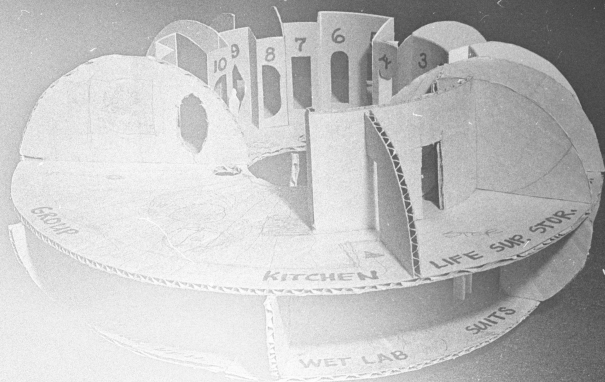




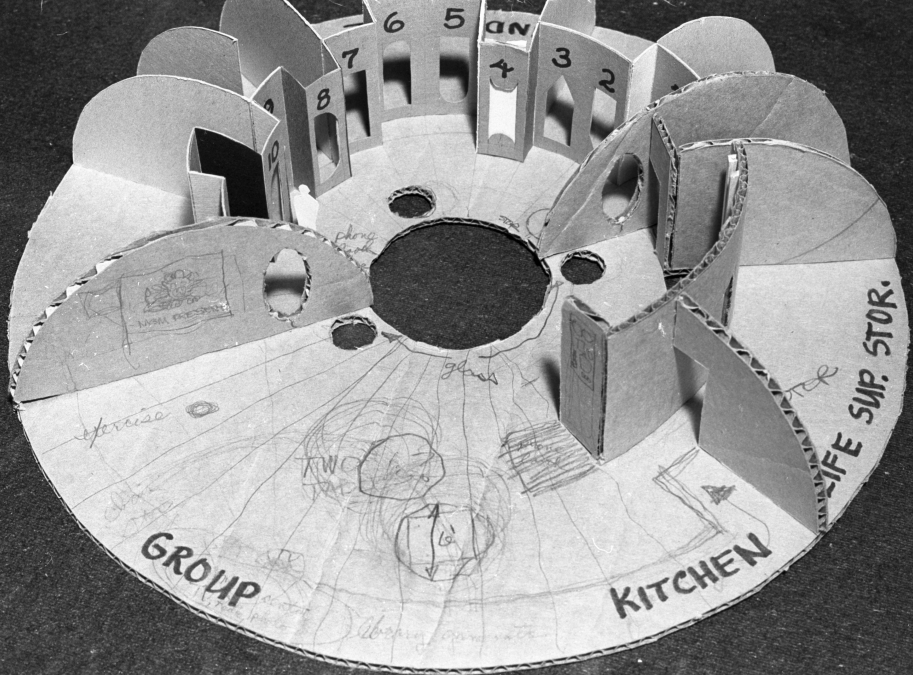
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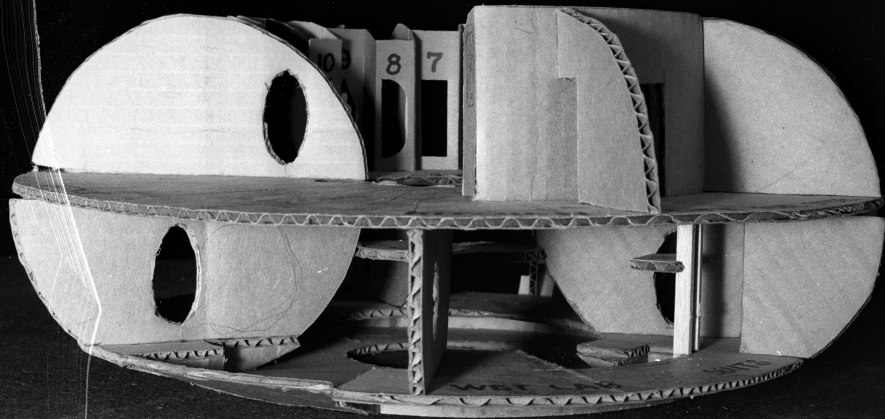


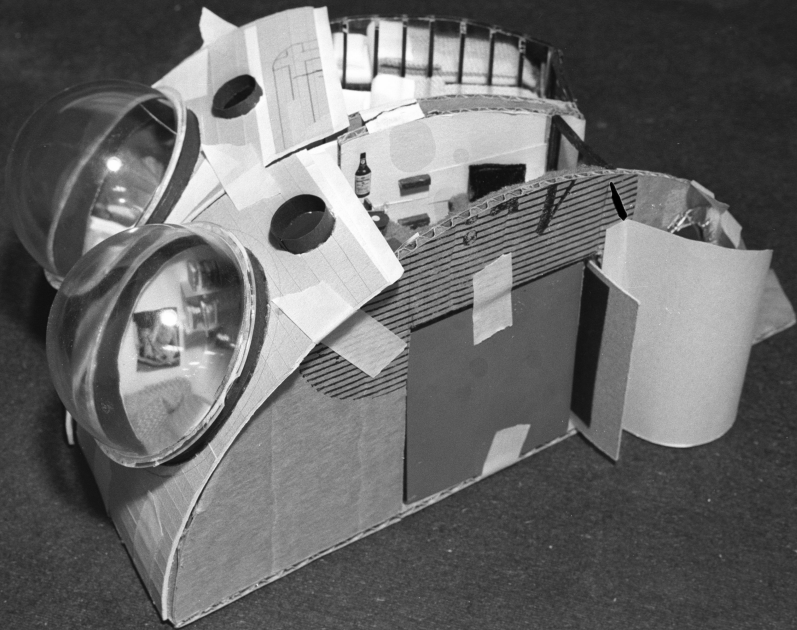


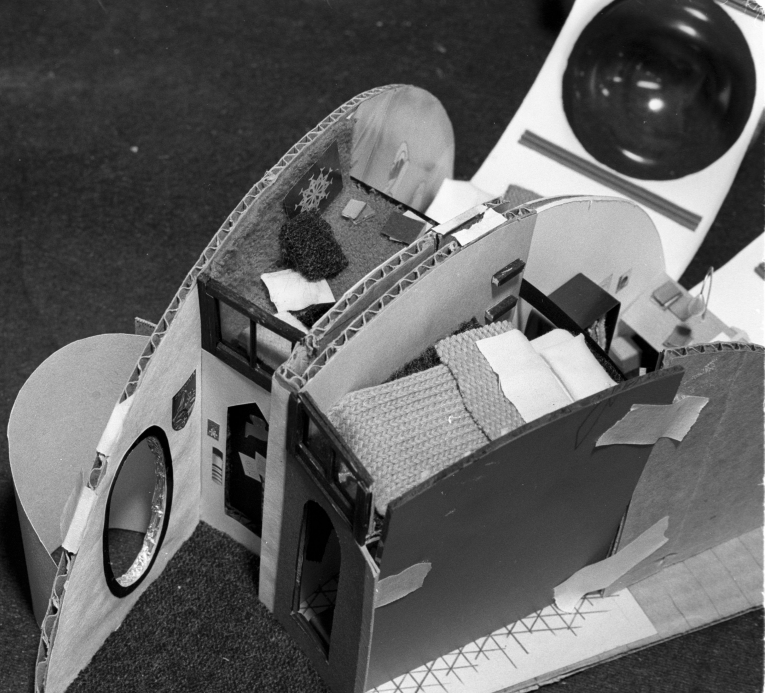




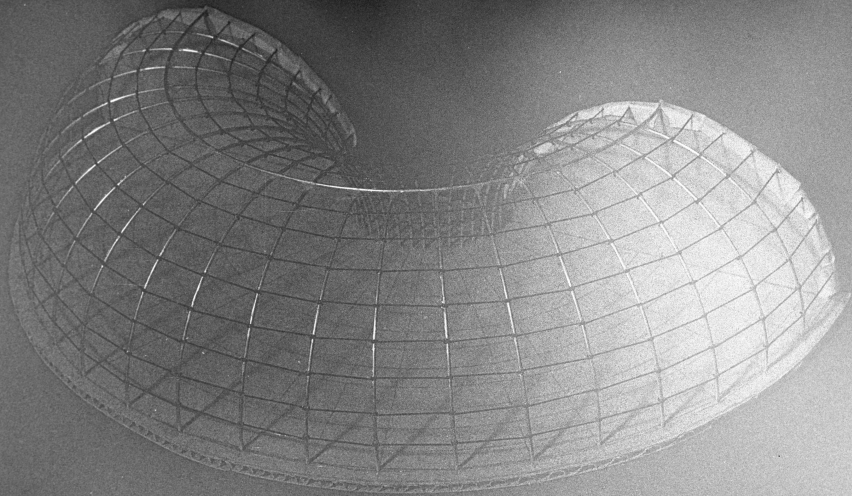


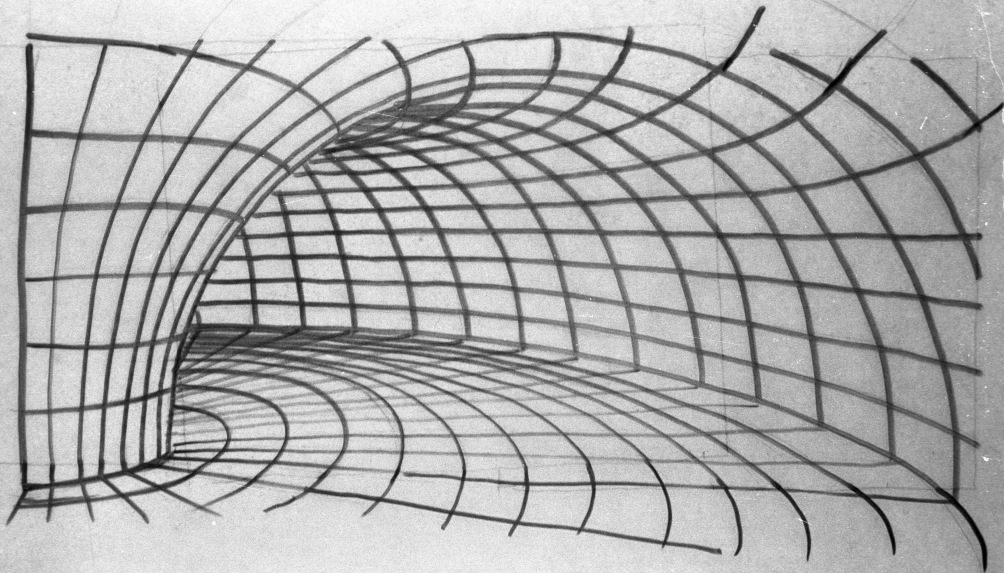












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