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BIOINSTRUMENTATION ACTIVITIES IN FOUR LOCALES

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An Introductory Note: *Clues to progress in bio-instrumentation, ~~are best~~ found by observing the laboratories where instruments are both developed and used in tackling the research and applications problems of biology. The following reports ~~on~~ visits to four locations, ~~provide some~~ hints on how successful bioinstrumentation can be carried out in exceedingly different environments. ~~All~~ have one thing in common, however: a dependence on close and meaningful association between the life scientists (who have the problems) and instrumentation specialists (who are keen to participate in biological matters). Future BIAC Modules will present observations on other kinds of Laboratories in an attempt to cover more of the ever-widening spectrum of creative instrumentation in the broad field of experimental and applied biology. Any reader with unusual and/or rewarding applications of instrumentation in his laboratory is invited to forward material for this series.*

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BIAC LABORATORY VISIT

No. 1

Place: *Biophysical Separations Laboratory, K-703*
Oak Ridge Gaseous Diffusion Plant

Time: *Friday, 26 November 1965*

A Bio-Engineering Program of major dimensions is under way at Oak Ridge, Tennessee in the newly organized Biophysical Separations Laboratory which is being operated for the U. S. Atomic Energy Commission as part of the Oak Ridge Gaseous Diffusion Plant (K-25) by Union Carbide Corporation. The Laboratory is housed in the old and sizeable electric power generating plant which provided power for K-25 -- about one-half mile distant from the huge uranium isotope separation plant. At the present time a fraction of the floor space of this multi-story building is already occupied with personnel offices and laboratory. The old generators are being dismantled and will free more space for the continued expansion of this new Oak Ridge effort which is expected to take place.

Mission of Program

The Biophysical Separations Laboratory grew out of the very successful development of the zonal centrifuge at Oak Ridge, which was funded jointly by the NIH and the AEC starting in 1962. The improvement and application of this technique involved increasing collaboration between biologists in the Biology Division of the Oak Ridge National Laboratory and engineering people from the Technical Division of K-25. In time a systematic research program was organized involving these two groups and a broader mission became apparent: namely the development of a new technology for the separation of subcellular biological materials. At least two goals are inherent in this mission:

1. The development of techniques which will permit a visualization of the cell as a spectrum of separated particles.

2. The creation of new techniques of physical instrumentation and automated chemical analysis to quantitate these substances.

The startling implication of this work, however, is its pointing towards the basic development of a new technology which could very well lead to industrial processes for concentrating useful quantities of various subcellular biological materials (e.g. difficult if not impossible to synthesize complex molecules and multimolecular structures such as mitochondria, chloroplasts and chromosomes). How these materials will be used in a new field of "Biological Materials Science" is exciting to visualize...certainly parallels can be made between the circuit building of present day microelectronic solid state physics and the possible development of synthesized biomolecular structures. It was quite clear to this visitor that the key people involved in this significant development at Oak Ridge are indeed thinking in terms of such long range possibilities -- a conversion of effort at that facility which may one day see sizeable production-process plants handling biological materials as well as isotope separations in the Tennessee hills.

Personnel

The new laboratory is headed up by Dr. Norman G. Anderson, a Molecular Biologist from the Biology Division of the Oak Ridge National Laboratory. A fairly small permanent staff has moved with him into the Laboratory. However, the effort underway has involved participation by engineers from K-25 as well as colleagues from the Biology Division and professors and graduate students in a few universities. The spectrum of associated researchers (gathered from names on published reports on work done) includes:

Thirteen (13) process engineers from the K-25 Technical Division involved in the developmental phases of the centrifuge program

Five (5) instrumentation specialists who continue to work on new instrumentation for the program

Three (3) electron microscopists assaying results of techniques developed

Four (4) computer specialists from K-25 central data processing facility

Four (4) metallurgists who worked on the centrifuge design

Four (4) chemists who worked on the chemistry of gradient materials

Four (4) engineers who operate the experimental systems

Six (6) collaborators from the Biology Division who have evaluated developments of the program

Specific Activities

Thus far, the activities of the Laboratory seem to have centered on three major areas:

1. The design and development of the zonal centrifuge as a separation technique. Projects have included:

   -evolution of a basic theory for the technique
   -development of low speed rotors
   -development of rotors with removable seals
   -design of rate-zonal and isopycnic-zonal centrifugation
   -computation techniques for sedimentation coefficients
   -design of a continuous flow centrifuge system
   -calculation of density and viscosity of gradient solutions

2. Applications of the zonal centrifuge technique. Projects:

   -separation of subcellular components and viruses by combined rate- and isopycnic-zonal configuration
   -isolation of rat liver glyocgen
   -isolation of paramylon
   -isolation of oral structures
   -lipid peroxidation
   -extraction of contractile proteins
   -respiratory syncytial virus isolation
   -isolating unusual particles in human plasma
   -isolating rat macroglobulins

3. The development of additional methods for separating and quantitatively identifying subcellular materials. Some techniques investigated or under development include:

   -a method for ultrarapid freezing of subcellular particles in which small droplets are centrifuged at high speed through liquid nitrogen.

   -high pressure column chromatography -- capable of performing separations at 400 lb-in^2 (psig). This has been applied in the separation of bases, nucleosides, etc.

   -an automated carbohydrate analyzer consisting of a continuous carbohydrate solution fractionation column which produces an elute in borate form that is processed by phenolsulfuric acid colorimetry. Full standard runs on solutions with up to 15 components are completed in less than 12 hours.

   -a continuous flame ionization analyzer for determining carbon in liquid streams or solid samples. Samples are fed on a continuous loop of iridium-rhodium wire which passes through the flame detector. Rapid instrument response time permits individual analysis of single cells, spores and dust particles closely packed on wire.

   -development of a completely contained laboratory in which purification by continuous-flow centrifugation, rate-zonal centrifugation, and isopycnic banding may be carried out. Unit, which has over 32 rubber glove access ports, has an automatically programmed sterilization cycle and an incinerator on its exhaust line.

Other Achievements

In addition to the development of the powerful techniques described above and their use in proven research applications, the program has opened up an important new frontier in the detection and isolation of trace amounts of virus which may be present in tumors. Experiments with zonal centrifuging have made it possible to trace amounts of virus to normal tissues and then recover them in a high state of purity. This is expected to lead to the preparation of vaccines that contain only virus particles, specific cell antigens, or viral subunits. Dr. Anderson cites other reasons why this program continues to push to the limits of available theory and technology in separating the constituents of cells. "If enough detailed information on the structure and composition of cells and on changes occurring from injury, disease, or during the cell cycle is assembled...this will throw into bold relief our need for an adequate theory or model of the cell into which available data may be fitted. Additional reasons related to basic biochemical or clinical studies are also not difficult to enumerate. However, the most valid and compelling reason for creating new methods for probing living cells still remains our simple curiosity."

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BIAC LABORATORY VISIT

No. 2

Place: *Biomedical Instrumentation Laboratory*
Northwestern University Medical School

Time: *Friday, 10 December 1965*

This relatively small but highly productive instrumentation R&D laboratory is located in the basement of the Searle Memorial Building in the medical complex right by the lake in Chicago's near north side. It is directed by Mathew L. Petrovick, a graduate electrical engineer who has devoted himself to biomedical problems during the past ten years after ten prior years in the electronics industry. He is assisted by a bioengineer, two technicians and one model maker and is currently looking for an additional bioengineer and an additional two technicians to help meet the increasing demands for services to the various biomedical programs at Northwestern. The laboratory has no spectacular features: it contains the usual workbenches and electronic test equipment. The unusual thing about it, however, is its remarkable productivity and its modest cost for services -- items which will be discussed further at the end of this report.

Current Projects

Requests for instrumentation and devices for both research and clinical applications come to the Laboratory from various branches of the hospital as well as academic departments -- including the newly organized Biomedical Engineering Center at Northwestern. A partial list of current developments includes:

a) Jaw Pivot Point Measurement ... a transducer is in development which follows the lower mandibular movement in order to plot the true neutral pivotal -- so needed in understanding individual jaw dynamics and for mouth prostheses. A test system permits the motions from this transducer to be optically transmitted to a remote photocell marix pattern recognition screen. The use of a computer to solve this pattern recognition problem is now being worked on.

b) Psycho-Sensory Test System ... an automated, remote control, test console has been developed for studying the response and behavior of "non-communicating" youngsters. Stimuli, provided from taped programs, are visual and auditory and the system responds to performance much like a teaching machine and automatically provides a statistical score. It has successfully detected children with sensory rather than mental inhibitions and has been used in overcoming language disorders. Its possible use as a remedial or teaching tool for aphasia victims is suggested.

c) Tongue Motion Measurement ... an ingenious transducer has been developed to study the relationship of tongue movements to speech and language difficulties. It consists of a palate mounted plate which picks up its information by capacitance variations. Tongue movements are projected on a scope where a matching process is

carried out by the therapist and patient. Five channels of information are being built into this transducer, which may ultimately telemeter its information: tongue motion; pharyngeal wall motion; position of two sides of the oral cavity; a piezoelectric microphone for acoustical speech within the cavity; a thermister for oral respiration. This kind of "integrated" transducer is typical of the sort of multiple measurements which may be necessary to gain a useful picture of a clinical problem. The approach has been used in studying cleft palate and the slow speech of Parkinsonism.

d) Heart Sounds Analyzer ... an automated test station has been built which will be used to screen 10,000 children for potential heart problems in January. The console, through a 30 second application of a chest microphone, provides a digital readout and/or taped record of heart acoustics. It counts frequency, sounds and murmurs, classifies them, and compares the values to statistical norms. The machine then displays out an analysis on nixie lights.

e) Pulmonary Work Computer ... this is a development by one of the Bio-Engineering graduate students at Northwestern which is moving towards a clinically useful stage. It is an on-line special purpose small computer which provides a figure of merit on pulmonary stress in breathing before and after surgery.

f) Parkinsonism Lesion Generator ... a system to localize the application of an RF induced lesion in the brain to treat Parkinsonism has been developed. It monitors the progress of the lesion by tonal measurements to permit precise control of its area.

Some Comments

The above are only a few of the projects which the writer was able to discuss with Mr. Petrovick during a brief visit. Not mentioned, for example, is the program of collaboration his Laboratory has developed with Dr. Wolfson in the Biology Department at Northwestern which is leading to the use of microminiaturized implant telemeters to study the EEG of small birds in behavioral and orientation research. It is obvious that this small Laboratory R&D group is not only coping with an unusually wide variety of sophisticated instrumentation development problems, but that a large measure of creativity is furnished in approaching these problems. A brief review of the modus-operendi of the Laboratory may furnish some clues as to its success:

1. The Laboratory offers services to all requestors at a fixed $6. per man hour fee, which is usually provided from research grants. It has no other source of income...but must collaborate with the biomedical investigators in the pre-proposal conceptual stage if it is to be funded.

2. Members of the Laboratory attend Clinic sessions at the Hospitals (usually held once a week) to participate in a study of the problem area where they are being called upon to help.

3. Personnel in the Laboratory are provided educational materials and encouraged to attend courses in physiology, anatomy and neuroanatomy. The ability of personnel to talk directly to M.D.'s with the problem is emphasized.

4. Mr. Petrovick has found that while electronics is a strong background base for useful personnel in this area, some specialized training in solid state circuitry, analog and digital computation and logical systems design is exceedingly valuable. Such a background can be had, for example, in technicians from serious post high school Technical Institutes such as DeVry in Chicago. This ability in his present two technicians is reflected in the several automated and computer-oriented type of biomedical diagnostic and test equipment being developed by the Laboratory.

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BIAC LABORATORY VISIT

No. 3

Place: *Texas Medical Center, Houston, Texas*

Time: *20-21 January 1966*

This tour of one of the major medical research and educational Centers in the United States was made in the company of the late Dr. Frank Haahn, a BIAC Council Member, who suffered a fatal heart attack only three weeks later. We are deeply indebted to Dr. Haahn both for his time and kindness on this visit as well as his outstanding knowledge of bio-instrumentation and its applications. The field suffered a great loss with his death.

A sizeable complex of buildings and facilities comprise this Center, which is located a few miles from downtown Houston. Some of the major units include:

Baylor University College of Medicine
Ben Taub General Hospital (Clinical unit of Baylor)
M. D. Anderson Tumor & Research Institute (U. Texas)
Houston State Psychiatric Institute
Texas Institute for Rehabilitation and Research
Methodist Hospital
Veterans Administration Hospital
Texas Medical Center Common Research Computer Facility

In addition to the fully medically-oriented Institutes, Rice Institute (with its developing bio-engineering interests) is just adjacent to the Center and faculty at the University of Houston are becoming increasingly affiliated with people and programs at the Center. Further, the new NASA Manned Spacecraft Center, which is about 30 miles southeast of Houston, is involved with the Center in joint and funded research programs related to the medical and ecological problems of manned space missions.

Common Computer Facility

A good way to start exploring the many aspects of bio-instrumentation now underway at the Texas Medical Center is to first visit its recently established central computing facility, located in the second basement level of the Center's parking garage. This facility was established with a grant from NIH augmented by funds by the University of Texas, Baylor University and local Foundations. It contains an IBM 7094 and IBM 1401 data processing systems, plus several auxilliary machines (keypunching, reproducing punching, etc.).

The most noteworthy thing about this Computing Center is that it is solely devoted to biomedical research. Its function is to provide large-scale computer support to participants on application for service. The Center is directed by Mr. Lynn C. Hayward and is overseen by an Executive Committee, composed of members from the three major Institutes (Texas, Baylor and the Center), with a University Liaison Committee as advisors. Since most of the Institutes in the Texas Medical Center have their own smaller

and specialized computers (e.g. Anderson has a 1401 and SDS-930), the major function of the Computing Center is to handle the more complex research tasks involving major quantities of data. Increasingly this function is served through "satellite" hook-ups with the smaller computers in their outlying locations.

The TMC Computing Center is barely one year old, yet, we were informed, the 7094 is just about completely loaded and plans are already under-way for a new and even more capable computer. Time on the 7094 is sold at $400/hour and users must obtain approval for access to the machine by routing job requests forms through designated institutional reviewing committees. The users are required to prepare their own input punchcards. The operating system of the Center is the standard IBSYS processor and includes most of the well known compilers, assemblers and utility packages (e.g. FORTRAN IV, COBOL, IBMAP, FORTRAN II, Commercial Translator).

Some of the research projects currently involving the Computing Center include:

- Pilot studies of physiological parameters in anesthesiology in "real time" (see later notes on work by Boyd & Wilber at M. D. Anderson).

- Microwave transmission of electrocardiogram (over distance of 1/4 mile) to the 7094 to predict cardiac arrests in patients at M. D. Anderson.

- Data handling for laboratory automation project at Anderson.

- Analysis of unique periodicities in the EEG in study being conducted by Dr. Neil Burch at Houston State Psychiatric Institute.

- A long-range study of the effects of changes in environment on the physiology of normal subjects being conducted at the Texas Institute for Rehabilitation for NASA by Doctors Vallbona and Vogt (see notes).

- Analysis of performance measurements in simulated study of 14 day Appolo mission being conducted by Dr. Lipscomb of Baylor.

- Development of data handling techniques and system for individual medical records for NASA.

M. D. Anderson Hospital and Tumor Institute

The visit here centered on the work being carried out by Dr. W. A. Boyd and Dr. S. A. Wilber of the Section of Anesthesiology in the use of an on-line computing system to monitor patients during surgery. A complete spectrum of physiological variables, including pCO_2 and pO_2 of the blood, respiratory pCO_2, and venous pressure, will be collected by patient-worn sensors during surgery and brough to an analog-to-digital console which has been designed and perfected by Richard Smart, the Department's full-time

research scientist. Digital information is then processed in real-time by the Institute's 1710 computer. The intent is to develop, through dynamic information correlated with the actual surgical procedures and results, some predictive indicies which will permit an over-all evaluation of a patient in surgery at any particular moment. Aside from this valuable and practical clinical objective, Dr. Boyd expects to extend the project, using this excellent quantifying system, into fundamental studies of the effect of anesthetic depression on the central nervous system and other bodily functions. He would also like to explore the exciting notion that chemically induced metabolic depression may be useful during the post-operative recovery period as well as in producing a "hibernation" effect in people employed in long duration, low-performance occupations (e.g. extended space missions).

Another interesting capability at Anderson is its Bio-Mathematics Department, a major group including 45 people and headed by Dr. Lee D. Cady, Jr., formerly at N. Y. U., and well known for his early studies in the use of computers in medical research. As new facilities are designed at Anderson they will have integral computer access lines. As mentioned above, numerous large scale data collection and analysis projects are being carried out in this Institute which involve increasing participation by members of Dr. Cady's Department to overcome the difficult software development problem, and to help establish realistic mathematical criteria.

Baylor University Medical School

Doctors H. E. Hoff and L. A. Geddes have established over the past ten years a remarkable program for teaching the fundamentals of bio-instrumentation to medical students, biologists and engineers. Offered by the Physiology Department, the program is visible in three areas:

1- As part of the indoctrination in the regular physiology course for medical students.

2- As a six-weeks summer training course in basic biomedical electronics and basic mammalian physiology for "indoctrinating" researchers in both the physical and life sciences.

3- In a one-year program for advanced research people in the biosciences which mainly emphasizes applied mathematics, physics and electronics.

The laboratories which have been developed for these courses are a major reason for the program's success. There are a large number of small labs, all equipped with an integrated system of physiological monitoring stations and in touch, via a central control console, with neighboring medical facilities as well as each other. Hence the students can at any time witness and participate, through TV and voice links, unusual demonstrations or experiments being carried out. The heart of the student station is the Physiograph unit, developed by Dr. Geddes, which includes an array of sensors and all of the necessary electronic gear for multiple-monitoring of physiological variables during experiments and operations on small animals. A separate BIAC Educational Note is planned which will more fully describe this effort at Baylor University Medical School.

Aside from his continued improvement of biomedical instrumentation education at Baylor, Dr. Geddes has been deeply involved with the development of techniques which have practical clinical application. He has designed and constructed a rheoencephalograph for the Department of Surgery which is being used to monitor cerebral blood flow. Its novel aspect is its use of impedance as its measuring principle. Dr. Geddes has also been directly involved with Dr. Carlos Vallbona at the Institute for Rehabilitation in developing the bedside monitoring system which will be described next.

Texas Institute for Rehabilitation and Research

At the time of the visit over 3,000 patient monitoring hours had been logged on the system designed by Doctors Geddes and Vallbona and experimentally tested at this Institute. The sensors, which have been gradually adapted to become non-jiggling or detaching, provide blood pressure (programmed cuff with automatic accessories), respiration (impedance pneumograph), EKG and heart rate, temperature (rectal thermister). All are collected at a bedside console which displays digital and analog data to nursing personnel. The information can also be telemetered to a remote monitoring and recording facility and, if desirable, into a computing system for mechanized assembling of patient records.

The system was first tried out on iron lung patients at the Institute, which proved to be a very convenient "helper" to the nurses who attended these machines. This did much to sell the nursing personnel on the extension of the system into bedside pre-monitoring before surgery and in the recovery room. An excellent recent report on the experience gained thus far with the system is presented in the Proceedings of the 1965 National Telemetering Conference which is published by the Instrument Society of America, Penn-Sheraton Hotel, Pittsburgh, Pennsylvania.

Another major instrumentation-oriented project at this Institute is the work done by Doctors Vallbona and Vogt for the NASA Manned Spacecraft Center on the effects of prolonged bed rest on normal physiology. Some of the factors being observed are bone density changes, calcium losses, and cardiovascular alterations.

Veterans Administration Hospital

A Physiometrics Laboratory has been established at the VA Hospital in Houston headed by Dr. David G. Simons, formerly Chief of the Flight Medicine Branch at Brooks Air Force Base and a pioneer in high altitude physiology and in the application of physiological and psychophysiological monitoring systems. According to Dr. Simons, Physiometrics is the quantification of physiological response to controlled and measurable stimuli and it implies the use of modern automated data handling techniques including computer analysis. While Dr. Simons only arrived on the scene this past August, his laboratory already has the necessary input equipment associated with psychophysiological measurements and has acquired a PDP-8 Formater which will essentially provide an incremental digital tape record of the measurements made and present these to the IBM 7094 at the Medical Computing Center. To date, he has not related physiometrics to stimuli, but has used the term to combine the concepts of physiological activity and its measurement using computer techniques as an integral part of the analysis and

measurement. The critical factor may be the relationship of the patterns of multiple measures over a period of time, rather than a specific stimulus response situation.

Since Dr. Simons is only starting in his program in Houston, it is interesting to note the work he completed over the past few years at Brooks Air Force Base in high-speed digital physiological analysis. His work there centered on collecting and analyzing heart rate and respiration data from pilots and passengers in a series of flights, simulated flights, sleep studies, circadian rhythm experiments, monitored psychiatric interviews, and observations on normal individuals involved in a series of stress tests. Programs were written and test runs made to identify slow-wave vs. respiratory heart rate reflex patterns. This monumental work was one of the most intensive applications of monitoring bio-instrumentation yet made and certainly will become a classic study of stress physiology.

Still another enthusiastic and highly-productive M.D. advocate of bio-instrumentation was visited at this VA hospital: Dr. Thomas B. Watt, who is Director of the Cardiovascular Research Laboratory. Dr. Watt has been intensively engaged in at least three projects which should be of major interest to biomedical instrumentation people:

1. Electrocardiographic Studies of Arborization Block. Knowledge of the electrocardiographic consequences deriving from interruption of specific portions of intraventricular conduction pathways has led to a better understanding of the excitation process in both the animal and the human heart. Completed phases of this project have included (a) defination of electrocardiographic patterns of incomplete right and left bundle branch blocks, (b) determination of differing effects upon excitation patterns of anterolateral versus posterobasal subendocardial infarction, (c) description of epicardial electrical alterations associated with arborization block at the midseptal level, (d) ascertaining the relationship between left anterior arborization block and significant left axis deviation in the primate (baboon) in contrast to the dog, and (e) producing in both dog and primate combined lesions of left anterior arborization block and right bundle branch block - a pattern in which envelopment of the entire ventricular myocardium takes place from a posterior site. The above changes are not uncommon in human electrocardiograms; however, it is more probable that a smaller lesion higher in the conduction system yet interrupting essentially the same conduction pathways may be the actual culprit. Evaluation of this latter type of lesion is currently being investigated.

2. Arterial Pressure Curve Model. Specific curves of human brachial artery blood pressure versus time can be modeled in terms of a four parameter electronic analog, having elements of capacitance inductance, and resistance. These correspond grossly to the lumped parameters of compliance, inertance, and resistance in the vascular system. Such simulation may prove useful in evaluation not only of physiologic stresses (such as exercise, drugs, radiation effects, aging, space flight, or the like) but also of cardiovascular disease states (for example, secondary vascular changes in

hypertension). A presentation of the theoretical basis for this model, constitutes a part of a symposium on engineering and heart disease at the March, 1966 International Convention of the Institute of Electrical and Electronics Engineers.

3. Development of a Thermistor Flowmeter. Possible use of a heated thermistor to measure instantaneous blood flow is being explored. Variables to be evaluated include time response (and/or linearity) of the thermistor itself, effect of tube diameter, significance of blood temperature, limits of blood velocity which can be measured, physical properties of solution being measured (blood versus water, for example), etc. Recording of thermistor response to steady state flow is now feasible within limits of velocity and tube diameter. In addition, the effect of blood temperature can be compensated to a great extent by an operational amplifier network which senses and corrects for a bridge imbalance, thus measuring a variation in voltage rather than in resistance.

The important point to be made about the kind of things Dr. Watt is doing is to underscore how deeply he relies in his studies on techniques from engineering and the physical sciences -- and the kinds of contributions possible from the use of these techniques. Even more important, however, is the fact that the imaginative and productive use of these techniques required a deep knowledge of the problems -- the kind of knowledge which only a first rate research man usually has. The obvious conclusion is, of course, that we simply must do what we can to get more first rate medical and biological research people enthused about and equipped with background in modern instrumentation. Of course, this is perhaps what BIAC is all about.

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BIAC LABORATORY VISIT

No. 4

Place: *Sensory Systems Laboratory, Tucson, Arizona*

Time: *30 January through 3 February 1966*

The purpose of this visit was to observe at first hand some of the varied programs of research and bio-instrumentation development being conducted under the direction of Howard A. Baldwin, BIAC Council Member, at the Sensory Systems Laboratory. Only one of the days indicated, however, was spent at the Laboratory itself; the remaining time, exclusive of travel, was spent in the vicinity of the Laboratory's field station at Tastiota, on the Gulf of California in the state of Sonora, Mexico.

The Tucson Laboratory

Sensory Systems Laboratory was founded by Baldwin in 1961 to "extend the instruments and senses of the laboratory investigator to the variety of terrestrial, aerial, and acquatic environments in which animals normally exist". The concept for such a non-profit research institution grew out of Baldwin's background as an engineer and designer of specialized measuring systems for experimentation in the life sciences and his own deepening interest in studying sensory, motor, and other physiological behavior of animals under natural conditions -- with particular emphasis on sensory nerve coding, which took Baldwin to Massachusetts Institute of Technology for a year's study with Dr. Jerome Lettvin in 1964.

In early 1965 the handsome new facility which the Laboratory now occupies at 2700 West Broadway, high in the hills above Tucson, was completed. A single-story functionally designed unit, it provides 4,000 square feet of interior space including offices, and facilities for the design, assembly, and testing of miniature and microminiature electronic devices (micro-manipulators, micro-welding, vacuum deposition, etc.), and supporting machine and plastic fabrication shops. Adjacent to the Lab is a heated animal house, currently occupied by three sea lions, and a number of tanks for training and experimenting with medium-sized acquatic animals.

Aside from secretarial and clerical help, the following people work at the Tucson Laboratory:

Glen H. Ingle - Electrical Engineer and Instrumentation Designer
Ernest L. Morrison - Mathematician and Systems Engineer
Howard Jarmin - Electronics Laboratory Technician
Peter Baker - Research Assistant (Photographer, etc.)
Suzie Holz - Animal Behavior Specialist and Trainer
Dorothy Samson - Animal Behavior Specialist
Ronald Brown - Ph.D. Candidate - Chemical Engineering
Eldon Braun - Ph.D. Candidate - Zoology

Both Brown and Braun are graduate students at the University of Arizona, but are carrying out their thesis research as full-time employees of the Laboratory and under the direction of Mr. Baldwin, who has an appointment as a Research Associate with the Zoology Department of the University.

In addition to the Laboratory staff, active associates are Robert Hoag, Doctor of Veterinary Medicine, who performs most of the surgical work on animals, and Dr. Martin Williams, a Physiologist, who collaborates on some of the animal physiological aspects of the program. Also three members of the Laboratory are at present located at Cambridge, Massachusetts, working under the direction of Fredric Webster, studying the mechanisms involved in echo location by bats.

Current Projects

Some of the work now going on in the Laboratory includes:

1- An Air Force sponsored project, now over three years old, in the development of an artificial muscle consisting of a cylindrical bundle of fibres which expand along their longitudinal axis. While this has been a basic study with the objective of modeling various body functions, some extremely useful devices have been constructed, including a fibre-bundle actuated air-driven motor with very high efficiency. At present the Lab is also attempting to model arteries to study peristaltic muscle function and is developing the mathematics necessary for computer simulation.

2- Under contract to the Army Research Office, the Laboratory has developed experimental instrumentation and techniques for studying the effects of chemical repellants on the behavior of sharks using two-direction telemetry via sonic transmission.

3- The Office of Naval Research has sponsored the work in Olfactory Nerve Coding which took Mr. Baldwin to M.I.T. to study with Dr. Lettvin.

4- Also sponsored by the Office of Naval Research:

- The development of special tungsten-coated glass electrodes.
- Work with Dr. Ken Norris on the training of dolphins as instrumentation "carriers" for work in the open sea.
- The development of a method for observing the distances between fish in the study of schooling being conducted at the Museum of Natural History in New York under Dr. Evelyn Shaw.
- The study of the EKG in free diving animals, carried out in Norway above the arctic circle on greenland seal and harbor porpoises in collaboration with Dr. John Kanwisher of Woods Hole Oceanographic Institute.

5- A study, funded by Shell Development Corporation, on the fundamental aspects of telemetric signalling by means of mobile miniaturized instruments borne by pipeline fluid.

6- The Office of Scientific Research of the Air Force is sponsor of the work being carried out at Harvard on bat echo location involving some members of the Laboratory (see above) and jointly supports with ONR studies of animal bio-telemetry Mr. Baldwin is carrying out in the Gulf of California.

Tastiota Field Station

For the past year Mr. Baldwin has established and started to build up the capabilities of a Field Research Station for the Laboratory on the Gulf of California at Tastiota, Mexico, about 60 miles southwest of the city of Hermosilio in Sonora. At present the Station consists of a cabin, located with its own dock on a large protected bay about one-half mile in from the Gulf itself. A Volvo powered inboard motorboat, employed in two and three day expeditions into the Gulf, is also a property of the Lab, as is the Piper Cruiser which Baldwin uses for the three hour flight from Tucson (a landing strip is adjacent to the Cabin). Aside from the instrumentation which is housed in the cabin and used aboard the boat (portable and waterproofed bio-telemetering equipment mainly) the Station is currently being equipped with a Montgolfier type balloon with a two-person gondola which will be used for "hovering" research above schools of sea lions and whales in the Gulf -- the first of its type to be used for this purpose.

Associated with Mr. Baldwin at the Field Station is a local resident who serves as its caretaker and also as an active participant and guide in the program, Mr. Julio Ruiz. Mr. Ruiz, who has received no formal education in biology or science, is an extremely intelligent man who, in the past year, has managed to read and master a rather large series of books on animal behavior and field biology. Since Mr. Ruiz was born and raised on the Gulf and has made his living as a fisherman there, his knowledge of the area and its wildlife is unsurpassed. However, Baldwin considers him more than a guide and caretaker and is already starting to benefit from Ruiz's original thinking and energy in the research program he plans.

The Laboratory's Field Station offers an exceptional opportunity to study abundant animal life at first hand...and with the sophisticated techniques which have been developed in Tucson. Large herds of sea lions populate small islands within miles of the station -- a population count of over 1,000 was made on one such island during my visit. Porpoises and whales are constantly in the area and birds of many varieties densely cover the bay and shoreline. It is Mr. Baldwin's intent to employ animals, trained in his Tucson laboratory and equipped with telemetering packages, to assist him in tracking and observational studies of schools of dolphin and herds of whales and sea lions. He plans, for example, to use the boat and balloon in combination to follow dolphin and then, hovering unobtrusively above, lower acoustical equipment into a school to record sounds and photograph behavior patterns.

The superb natural environment of the Field Station, its growing roster of specialized equipment and instrumentation, and, especially, the presence of the remarkable Mr. Ruiz, all add up to the possibilities for an important laboratory for studying the natural behavior of marine animals which should be increasingly heard from in the years ahead. Mr. Baldwin intends to offer the use of these facilities to visiting senior scientists and hopes to have several biologists associated on a periodical basis with the Laboratory at all times in the years ahead.

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