Alfred Korzybski Memorial Symposium 1959

NEW FRONTIERS IN BIOPHYSICS, SPACE SCIENCE, NEUROLOGY AND PSYCHOLOGY

ON THE SYMPOSIUM THEME 'EXTENDING THE PARABOLA'

William Exton, Jr., New York

The parabola has a special and deep significance to students of General Semantics; it is the symbol of the infinite possibilities of finite human knowledge.

The wonder and fullness of life and the boundless frontiers of science are both aspects of the same infinite variability of nature. The intuitive poetic recognition that no two grains of sand are perfect twins is the other side of the coin that bears the motto of all science: SEEK!

To this age-old recognition of the inevitability and the significance of differences, Alfred Korzybski added a potent codicil; and one that extends the principle to a new and fundamental usefulness in the understanding of human mentality. He demonstrated the essential relation between the perceived, and the perceiver, and the perceiver's resultant symbolic behavior.

Korzybski pointed out the linkage between the 'event,' the nervous system, and the verbal evocations. He emphasized our behavior in uttering sequential 'labels' of increasing abstraction; and reminded us that the remotest of these must still refer to that 'process' of which the characteristics are abstracted in the pre-verbal phase.

Representing this pregnant message in visual form, he created the Anthropometer, or Structural Differential; and taught us to use it to help clarify our own 'inside-the-skin' functioning in relation to the world 'outside-the-skin.'

Seeking a visual symbol of the infinite to represent the process or event with its indefinitely great number of characteristics, Korzybski utilized the parabola, with its opening extending upward. As he presented it, the partially enclosed area bore a limited number of holes or dots, in token of characteristics, distributed over the available space.

Crossing the axis approximately at right angles, some distance from the bottom of the curve, Korzybski placed the inevitable boundary to his symbol, in the form of a broken line. This broken line was his etcetera -- an invitation to recognize the existence of unspoken, unabstracted infinitudes that can never be fully represented.

For a generation, now, men have utilized this evocative symbol as Korzybski taught them.

As we indicate the abstraction of characteristics from within the fragmented parabola, we assume and imply the existence of characteristics in the area beyond the broken line; but perhaps there is also an implication that only the characteristics within the area shown can be abstracted. The applicability of the symbol is unarguable; we cannot abstract what we have no means of abstracting. Korzybski emphasized the many levels and orders of abstraction; the inferential submicroscopic (subatomic) as well as the macroscopic and microscopic levels and our verbalizations about them. He pointed beyond the broken line of the parabola where no characteristics were

'perceptible' by our available facilities -- and he reminded us that characteristics continue there, unnumerably and endlessly -- abstractable or not. He reminded us that such characteristics play their part on the event level, even if we remain incapable of perceiving their effects -- and so applying labels and dealing with them symbolically.

But now, perhaps the time has come to 'extend the parabola.' It is not for us to extend the 'infinite,' any more than we can create the characteristics that we are now only beginning to reach. But we can extend the area within our parabola -- 'break' it higher along the axis -- to symbolize our growing capacity to abstract characteristics always hidden from us before.

New tools and devices, new techniques and skills have given us new and better eyes and fingers. New mathematics and hypotheses, new discoveries and insights, new developments and principles have given us some of the means we need for projecting order and relation to our new observations, and for exploring their structure with ever expanding predictability.

Truly, the content of our parabola is growing constantly; and we are constantly catching glimpses of characteristics, utterly unknown before, just at the 'advancing edge.' Today, we are enlarging with accelerating speed our ability to better map the little known; and to map the hitherto unknown for the first time; and this because we are Extending the Parabola -- our symbol of the infinite characteristics of universe, the potentials of human mentality, the open-endedness of science.

Our Symposium on New Frontiers in Science came about largely through Mr. Exton's suggestion of 'Extending the Parabola' as theme for the Alfred Korzybski Memorial Meeting in the 25th anniversary year of Science and Sanity. Mr. Exton then set down this expression of his thinking-feeling about the significance of the parabola which Korzybski used in the epistemologic model he originated in 1923 in connection with his definition of man as a time-binding class of life. The model, first called the Anthropometer, was renamed the Structural Differential in the course of Korzybski's study and writing which culminated in Science and Sanity. Mr. Exton did not intend his discourse to be an exposition of the Structural Differential; it is fully described in Science and Sanity (1933) and the earlier Time-Binding: The General Theory (1924-26) to which persons unfamiliar with the Differential are referred. -- M. Kendig

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WILLIAM EXTON, JR., a consultant, primarily to management, in problems related to communication, is senior member of William Exton, Jr., & Associates, owner of Exton-Aids (audiovisual materials) and Exton Plantations (Dover Plains, N.Y.), president of the Institute of Human Communication, trustee of the Institute of General Semantics, author of Audiovisual Aids to Instruction and other books, many articles in professional journals, and the series of recordings called Growth of Democracy. He was born in New York, graduated from Harvard (BA 1926) majoring in political science, attended Korzybski's seminar in summer 1947, participated in many post-graduate studies and received the MA from Teachers College, Columbia in 1950. He is an associate with faculty status in the Columbia University Seminar on Organization and Management and teaches special courses at New York University. During his World War II service in the Navy he rose to the rank of Captain, USNR. He planned and directed the Training Aids Development Center for which he was awarded a citation for pioneering new areas of training and indoctrination, served in the North Atlantic and commanded a LCI group and then a gunboat flotilla in the Pacific receiving two awards of the Bronze Star for his combat activities.

From the Program

ALFRED KORZYBSKI MEMORIAL SYMPOSIUM
New York, 11 April 1959

Previous Alfred Korzybski Memorial Meetings, 1952-58, have been planned around a single lecturer.

To mark this 25th anniversary year of Korzybski's Science and Sanity, the Committee decided to offer a Symposium of creative workers whose investigations and findings have changed notably pre-existing notions of certain portions of our universe -- disclosures from which men must inevitably derive new constructs and abstractions about their universe and the organisms which people it.

The theme of the Symposium, 'Extending the Parabola,' takes its significance from Alfred Korzybski's Structural Differential. In this model of the 'nature of things' and of the processes of communication characteristically used by humans looking toward more or less predictive and adaptive ends, formal representations are provided for the 'non-verbal events' of the universe taking place at the macro- micro- scopic and inferential submicroscopic (subatomic) levels. To such happenings (and ultimately to them alone) our neuro-musculo-glandular apparatus responds. To represent these aggregated interrelated 'events,' Korzybski used a parabola with its opening extending upwards. Thus symbolically the parabola accomodates for all time changes in the structure and details of our 'knowledge.'

The Symposium participants have richly contributed to 'extending the parabola,' helping to open up new frontiers of exploration and 'knowledge.' They will report on these contributions and their significance to man and society as they view them. For the Panel, Professors Wendell Johnson and Russell Meyers will join the speakers in discussing their contributions and will attempt to interrelate and interpret them from Korzybskian viewpoints.

CHARLES MARC POMERAT, Professor of Cytology and Director of the Tissue Culture Laboratory of the University of Texas, Galveston, was born in Southbridge, Massachusetts. He earned the AB degree at Clark University in 1932 and took his AM and PhD degrees at Harvard in 1934 and 1937. He studied at the University of Buenos Aires, Argentina and Cambridge University, 1937-38, as a Rockefeller Foundation Travelling Fellow. His earliest teaching and research in biology was at Clark and Rutgers Universities. In 1939, he went to the University of Alabama as Associate Professor and became full Professor and Head of the Department of Biology in 1940, posts which he held until 1943, when he became Professor of Anatomy of the Medical Branch of the University of Texas. In 1945 he advanced to his present post. In 1942-43 he conducted research for the Bureau of Ships, United States Navy, under contract by the Oceanographic Institute, Woods Hole, Massachusetts. He is a member of many scientific societies in this country and abroad, has published some 200 papers and held various editorial posts. Professor Pomerat's contributions cover a number of areas in biology, notably immunology and biochemistry. His studies revealing the hitherto unsuspected dynamics of the neuron and other cellular elements of the nervous system have earned him world-wide renown, and are the subject of his Symposium lecture.

WILLIAM JUSTIN FRY, Research Professor of Physics in the College of Electrical Engineering and Head of the Biophysical Research Laboratory of the University of Illinois, was born in Johnstown, Pennsylvania and took his ScB and ScM degrees in physics at Pennsylvania State University in 1940 and 1941. During World War II he was engaged as Research Physicist at the Naval Research Laboratory, Washington, D.C. where he was responsible for a number of advances in the use of sonar. In 1946, he became Assistant Professor of Electrical Engineering at the University of Illinois, Urbana. The laboratory he now heads has attracted international notice for its basic work in the effects of ultrasound on the central and peripheral nervous systems. His earlier researches included supersonic detection of infra-red irradiation; piezo-electric crystals; sound; and the design of crystal vibrating systems. Since 1949, he and his associates developed a high-energy sound apparatus by which selective lesions of any desired shape and orientation can be produced in the nervous system, discriminating among nerve pathways, nuclear aggregates, supportive tissues and blood vessels. This work and its significant potentials for neuroanatomy, neurophysiology, physiological psychology and clinical neurology are described in his Symposium lecture.

JAMES ALFRED VAN ALLEN, Professor and Head of the Department of Physics of the State University of Iowa, is a native of Iowa. He took his BS degree at Iowa Wesleyan College in 1935 and his ScM and PhD degrees at the State University of Iowa in 1936 and 1939. The following two years he was a Carnegie Research Fellow in terrestrial magnetism at the Carnegie Institution. From 1941 to 1946 he was engaged at the Applied Physics Laboratory of Johns Hopkins University and the Office of Scientific Research and Development of the United States Navy, his endeavors relating to nuclear physics and light particle reactions; cosmic ray research in the upper atmosphere and above; ozone in the upper atmosphere; and techniques of research with high altitude rockets. He was conspicuously instrumental in conceiving and implementing the International Geophysical Year (July 1957-December 1958). In January 1959 he was presented with the U. S. Army's Distinguished Service Award. Professor Van Allen returned to the State University of Iowa in 1951 as Head of the Department of Physics. There he has pursued his earlier interests and with the advent of newer telemetering instruments devised by himself and his colleagues he has revealed the existence of two zones of relatively intense radioactivity surrounding the earth, which he discusses in his Symposium lecture.

RUSSELL MEYERS, MD, FACS, Professor of Surgery and Chairman Division of Neurosurgery, State University of Iowa; Chief Consultant in Neurosurgery of the Veterans Administration Hospital, Iowa City, was Chairman of the Symposium and Panel. He was born in Brooklyn, received the BA and MSc degrees from Brown University and the MD from Cornell University Medical College. His hospital appointments include Brooklyn, Kings County (N.Y.), Bellevue, Lahey Clinic. He has taught at Brown University, New York University, Cornell Medical College, Columbia University, Long Island College of Medicine, University of Denver, and University of Cincinnati. He served with the Army Medical Corps 1942-46 (Lt. Colonel), in the States, Ireland, England, and France. In 1946, he became Assistant Professor of Surgery and Chairman of the Division of Neurosurgery at the State University of Iowa and advanced to Professor in 1949. Dr. Meyers is an examiner of the American Board of Psychiatry and Neurology and was recently appointed chairman of the Advisory Council on Neurosurgery of the American College of Surgeons. His bibliography includes over one hundred articles. He has been a member of the board of both the International Society for General Semantics (president 1950-53) and the Institute of General Semantics, and is currently president of the Board of Trustees of the Institute (1957-). He is a Fellow of the Institute, member of the editorial council, General Semantics Bulletin and lectures at the Seminar-Workshops of the Institute. In 1939 Dr. Meyers conceived of and, for the first time, implemented the surgery of the basal ganglia, a group of deep-seated nuclei of the brain, which up to then had been considered technically unapproachable. His recent work with William J. and Frank J. Fry, using a new ultrasonic stereotactic instrument (described in W. J. Fry's lecture) carries a potential for opening new vistas in all surgical specialties.

WENDELL JOHNSON, Professor of Speech Pathology and Psychology, State University of Iowa, participated in the Panel Discussion. He was born in Roxbury, Kansas and took his BA (1928), the MA (1929) and PhD (1931) degrees in Psychology, Clinical Psychology and Speech Pathology at the University of Iowa, and was associated with the Child Welfare Research Station of the University. He became Assistant Professor (1937) and Professor (1945-), and Director of the Speech Clinic (1943-55). He was editor of the Journal of Hearing and Speech Disorders, 1943-49; president of American Speech and Hearing Association, 1949, and consultant, U. S. Office of Education, 1957-58. He is Chairman, American Speech and Hearing Foundation (1950-); Consultant in Speech Pathology, Walter Reed Medical Center (1954-); member of National Advisory Council on Vocational Rehabilitation (1957-); Editor and Chairman of Committee on Publications, American Speech and Hearing Association (1959-). Dr. Johnson's interest in general semantics was prompted by reading Science and Sanity in 1936 and by seminars under Alfred Korzybski, and through the years he has incorporated its principles in his teaching and research. His books include People in Quandaries and Your Most Enchanted Listener. He was president of the International Society for General Semantics 1945-47 and has served on the Board of Trustees of the Institute of General Semantics.

(Professors Meyers and Johnson presented one-day seminars on the day after the Symposium.)

DYNAMIC ACTIVITIES OF CELLULAR ELEMENTS OF THE NERVOUS SYSTEM*

Charles M. Pomerat
Tissue Culture Laboratory
University of Texas, Medical Branch
Galveston, Texas

Whenever I have the honor of addressing a group like this for the purpose of describing some of the emerging opportunities of the field which is both my professional preoccupation and my hobby, I think of the small boy who was asked by his teacher to name the continents. He started out bravely, saying, 'There are five continents, the four most important of which are the following three: Europe and Asia.' I am obliged to follow the small boy's example and reduce an enormous and rapidly expanding subject to two major themes: (1) a description of some of the techniques being used to keep cells alive for various types of study; and (2) a consideration of the dynamics of living cells with special reference to the nervous system.

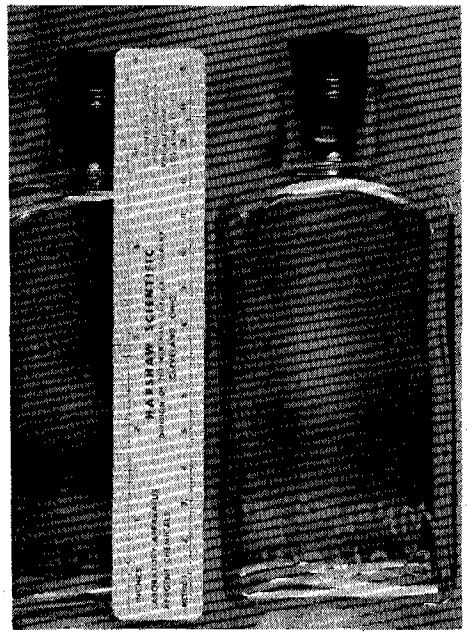

Figure 1

We can now keep human cells alive for indefinite periods of time in containers of the type exemplified in Figure 1. There are, of course, several other types of containers. In our laboratory we currently maintain 12 different species of human cells, one of which was obtained from a patient who died eight years ago.

We can transfer cultures at the end of a week from one bottle to approximately ten bottles. By the end of two weeks we can have 100 bottles, the 'floors of all of which are covered with layers of cells as illustrated in Figure 2. Thus, not only can we work with mass cultures, i.e., with milligrams of human tissue elements representing a great variety of cell systems, but we can separate one cell and 'plate' it out, much as does the microbiologist in handling bacteria. As a consequence, it is now becoming possible to deal with human cells in a manner comparable to that used by students of bacteriogenetics or neurosporogenetics.

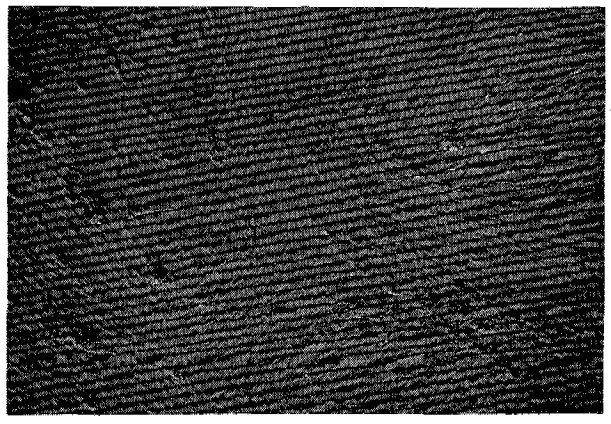

Figure 2

One of the great quests in the culture of animal cells has been for a completely synthetic medium. This has recently been crowned with success for one species of cells by workers in two different laboratories -- Parker in Toronto and Earle in Bethesda.

*N. B. In addition to a most illuminating set of lantern slides, Professor Pomerat used three intriguing motion pictures in illustrating his unique studies. The present abstract can in no manner do justice to the parts of his presentation in which the films were used. -- Editor.

The Canadian's formula provides a completely adequate diet for the L-strain of a subcutaneous fibroblast of the mouse.*

At the moment, we have no comparable completely synthetic medium for other types of cells. To produce such is one of the great challenges in the field of biochemistry as related to dynamic cytology.

In achieving long-term cell cultivation, something beyond the careful management essential to tissue culture is evidently involved. Figure 3 illustrates living, elongated spindle-shaped 'fibroblasts' from the synovial membrane of a man's knee. They grew for a considerable time in a rather symmetrical, orderly way, each cell closely resembling its fellows.

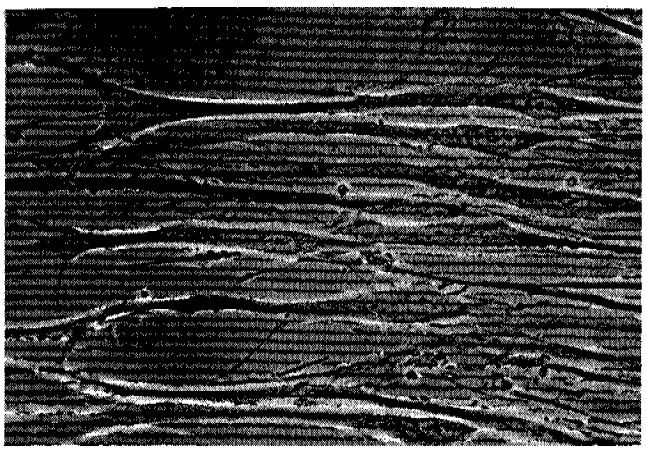

Figure 3

Then, quite suddenly, at a time when the culture had been growing rather more slowly than at the outset, the cells began dividing very rapidly. A morphological transformation reminiscent of the variation encountered by the pathologist in malignancy accompanied this change (Figure 4). It is not an implausible surmise that such transformation is closely related to the extraordinary phenomenon of malignancy, for the change of these synovial fibroblasts, like that seen in malignancy, involves an alteration in the number of chromosomes.

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* This formula was not available at the time Dr. Pomerat's text and figures were prepared for photo-offset. When it was received and copied, the formula far exceeded the space allocated for reproduction on this page. The formula is therefore printed in full on the final page of this transcription of Dr. Pomerat's lecture. -- Editor.

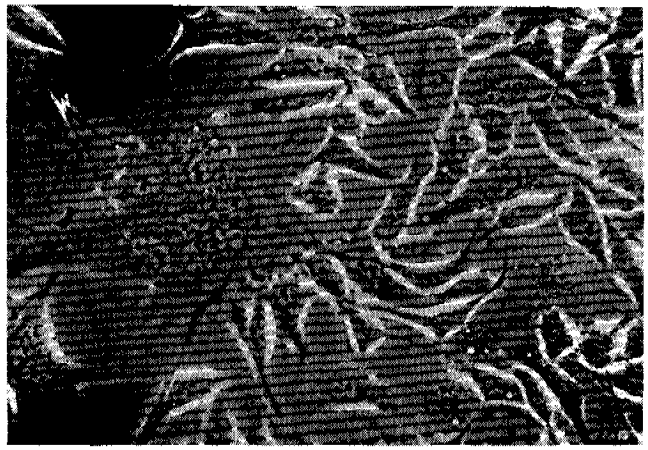

Figure 4

You recall that, characteristically, at the time of healthy cell division, a rather precise number of chromosomal bodies is duplicated. In mammals, these chromosomes are rather hard to see because they are so numerous and because they occupy a rather small volume within cells which, compared to those of, say, the amphibia, are themselves quite small. This difficulty can be to a considerable extent alleviated, for in tissue culture a cell of cuboidal form often 'settles down' and becomes quite flat (Figure 5). Such

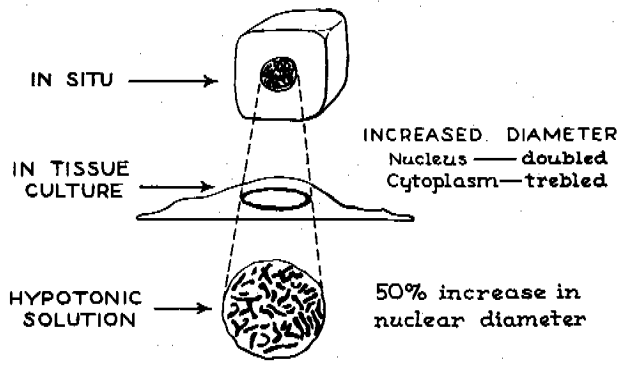

Figure 5

a flattened cell can be treated with a solution from which certain salts have been eliminated. As a consequence, the area where the divisional event of mitosis occurs is perceptibly spread out. It is then possible to examine the chromosomal bodies -- the bearers of hereditable features. Figure 6 shows the 46 chromosomes at a rather high magnification of a single cell from a human foetal spleen.

To return, now, to a further consideration of the transformation of which we were speaking, in which the number of chromosomes increases beyond that characteristic of the species, it appears that in some manner this additional number of chromosomes makes for facultative life outside the body. Once transformed

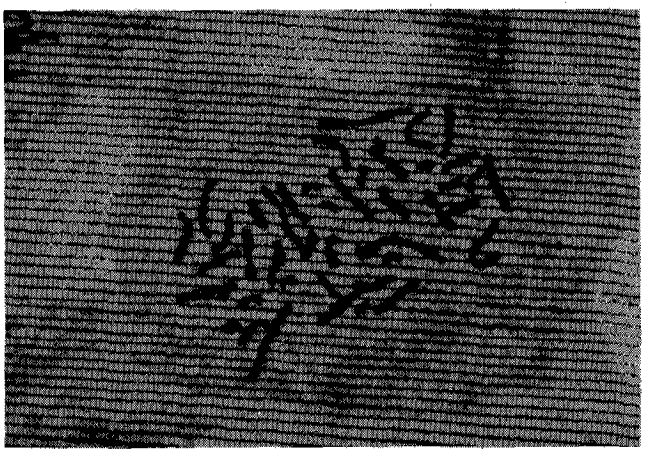

Figure 6

in this way, the cells continue to grow rapidly. They can then be fed a variety of media and their reactions recorded.

The following gives a list of the elevated chromosome numbers of certain cells, some of which were derived from neoplastic and some from normal elements.

Before looking at the moving pictures, it may be worth our while to review some of the architectural features of the cell that have been especially illuminated in the living state by recent studies making use of time-lapse, phase-contrast cinematography and electron microscopy (Figure 7). The combination of

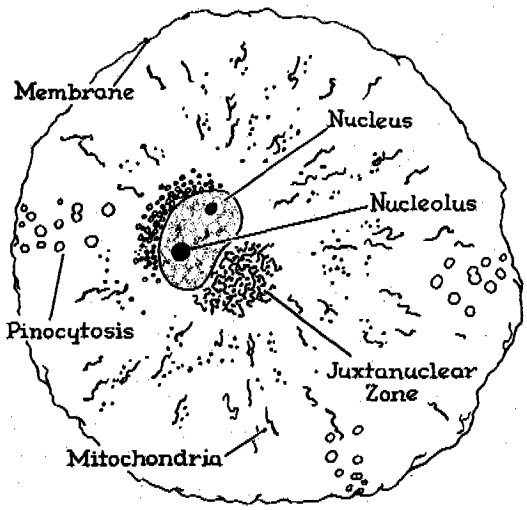

Figure 7

CHROMOSOME COUNTS OF CELL STRAINS (T. C. Hsu)

Origin	Total Cells Counted	Average Number of Chromosomes
NEOPLASMS		
S3 - HeLa	50	82
Maben	50	82
KB	50	83
J96	20	69
NORMAL		
Liver (Chang)	100	77
Conjuctiva (Chang)	50	82
Synovial fluid (CMP)	100	67
Foetal fibroblast (CMP)	58	69
Skin (Earle)	46	75±

As Darlington has suggested, these cells behave as if their nuclear control of the metabolic machinery of the cell, has been largely lost and taken over by the cytoplasm. Unrestricted growth of this sort does not lead to differentiation. It builds nothing in particular. Hence, organized development -- that miracle of the living world -- suffers gravely.

The relationship of these phenomena to the problem of malignancy lies beyond the scope of the present paper. I must move on, merely pointing to this as one of the exciting areas of currently emerging information.

these technics has posed many new suggestions and challenges for future investigators.

At the cell's edge we note an interface, the cytoplasmic membrane, a 'world' lying between the living substance of the cell and the environment. For many years moving picture technics have disclosed here the inward-migration of droplets of nutrient. This 'cell drinking' process, called pinocytosis by Warren Lewis, has been recently confirmed by use of the modern technics of fixing and preserving cells essential to fine structure study with the electron microscope. We now know that the passage of ma-

terials across the cell membrane is a far more dynamic and complicated process than that implied in the not too distant past by such terms as 'permeability.' The cell actually laps up the environment, engulfing nutrient materials in an extraordinarily active way. As a result of these disclosures, a new physiology of nutrition may be developed.

Another feature of keen interest are the mitochondria. These bodies are discoverable in all cells from protozoa to man. As you shall presently see, they move and writhe about in a striking way. They are believed to be the bearers, in the main, of oxidative enzymes -- important carriers of organic catalysts.

Yet another structure of the cell is the nuclear membrane. Formerly it was thought that this constituted a quite impenetrable barrier. We now know that there are perforations through the nuclear membranes of most cells; that the nucleus may turn and even spin; and that these mobilities of the nucleus probably subtend important exchanges of materials between the cytoplasm and the nucleoplasm.

The region of the cytoplasm close by the nuclear membrane is extremely 'busy' and has been referred to by Dr. Keith Porter of the Rockefeller Institute as the dynamic center of the cell. Workers with living cells often call it the 'juxtanuclear zone' and those working with fixed tissues have long called it the 'zone of Golgi.' Within it is a sort of coming-together of various organoids of the cells, including mitochondria, lipoprotein granules, fatty droplets, etc.

The apparatus by which our time-lapse, phase-contrast moving pictures have been made is pictured in Figure 8. In this setup we have a double moving

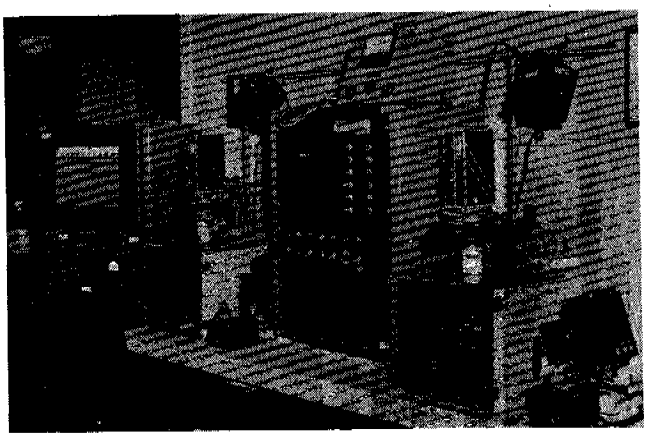

Figure 8

picture assembly. There are microscopes and incubators; above these are periscopes; and above the periscopes are Cine-Kodak cameras driven by rods from the timing device. We set the speed as we desire. Most of the pictures you are about to see were taken at one frame per minute. Projected at sound speed, the natural events are speeded up more than 1,000 times.

Our device includes a clock. Every time a picture is taken, a stroboscopic lamp illuminates the clock showing a number. This information falls on a prism and is printed on the margin of each film frame, thus permitting a later analysis of the activities of cells in terms of time.

We've now made some 300,000 feet of 16 mm. film, a few vignettes of which have been selected to give you the 'flavor' of the general properties of cells in action.

[The first film consisted of a number of sequences at a magnification of the order of 100,000 times normal in which the following structural and functional features were identified and commented upon by Dr. Pomerat:

- The time record (in hundredth parts of a minute)
- Relatively fixed cells
- Relatively mobile cells
- Highly mobile 'defensive' cells, including those which remove debris ('scavengers')
- The plasticity of the nucleus
- The mobility of the cytoplasm
- A single epithelial cell showing
  - cytoplasm
  - nucleus
  - nucleolus
  - juxtanuclear zone
  - mitochondria
  - fatty droplets
  - lipoprotein granules
  - undulating membrane at the cell margin
  - pinocytosis
- Fine, strand-like processes or branchings by means of which cells may inter-communicate
- Nutrients being swept into the juxtanuclear zone
- HeLa cell (from a case of carcinoma of the cervix of a human uterus)
- The difficulty of defining the cell's outer limits
- Ependymal cells from the lining of the ventricles of the brain showing many of the features listed above under single epithelial' cell but with special reference to the 'Golgi zone'
- Muscle (cross-striated) fiber with four nuclei
- Contraction and relaxation of striated muscle cells
- Cells from adult human nasal mucosa
- Nuclear spinning (at a rate, e.g., of 12 to 13 revolutions per hour)

Nuclear twitching
Mitosis (cell division)
prophase
metaphase
anaphase
telophase
Fibroblastic cells from granulating wound
Macrophage defensive cells from same wound]

The evidence from the studies exemplified above reminds us that, until the advent of tissue culture technics, most of our knowledge of cells came from fixed and stained, dead preparations. We have, then, been studying the science of death rather than of life. The newer data reveal that the organism is literally teeming with mobile structures and that we are living under very unsteady conditions. Equilibria are constantly being disturbed and reconstituted, reflecting the complicated exchanges that go on between cells and their environments.

Our films not only serve as teaching aids for students, but as research tools for a variety of analytical studies concerning the how, the why, the when and the where of the mechanisms underlying a number of living phenomena.

The analysis is considerably helped by making tracing paper reproductions of certain features of interest on the film frames, for example, the angle of rotation of a nucleus in relation to its nucleoli as a function of time (Figure 9).

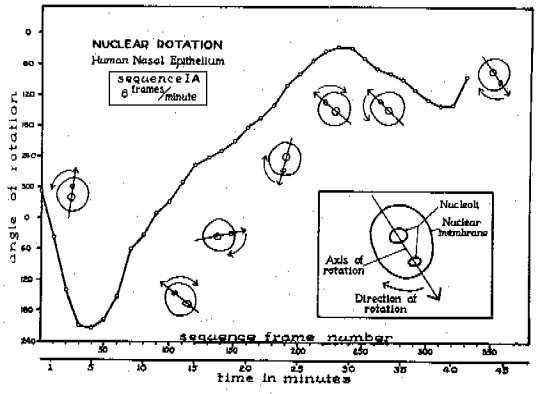

Figure 9

While opportunity does not permit our discussing the phenomena of nuclear rotation, I may say that we believe it has to do with protein synthesis.

In studying the nervous system we deal with two groups of elements -- the glia ('glue' or supportive-nutritive materials) and the neurones (the functional units of the nervous system).

The glia consists of two chief subgroups -- the astrocytes (star-shaped cells having numerous, multiple branches) and the oligodendrogliocytes (with sparse branches). The astrocytes are by far the most numerous cells in the nervous system. In addition, a number of scavenger cells, called microglia, abound among the glial and other neural tissues. They are derived from the mesodermal tissues, more particularly the blood-vascular elements, rather than from the ectoderm which gives rise to the glial and neural embryonic nervous system. Nevertheless, it is convenient to discuss the microglia along with the other two glial types.

[The second moving picture film consisted of a number of sequences at magnifications similar to those of the first film in which the following structural and functional features were identified and commented upon by Dr. Pomerat:

Astrocytes, protoplasmic type
Rhythmic contractions of astrocytes
Astrocytic twitching (pushing nutrients about?)
Undulations of delicate astrocytic cell membranes
Oligodendrogliocytes
Strong contractions of oligodendrogliocytes
The impaling of single astrocytes with (a) stimulating electrodes and (b) electrodes for detecting electrical potential changes within the cell. (These electrodes, fashioned and used by Drs. Hild, Chang, Tasaki and Mrs. Tasaki exhibit tips of submicroscopic dimensions.)
Two astrocytes 'joining forces' (the active approach of the branching processes and cell body of one astrocyte toward a neighbor exhibiting marked pulsatile activity).
Ependymal cells (a type of glial cell which lines the ventricular compartments of the brain and other derivatives of the embryonic neural tube).
Active cilia of ependymal cells (seen in adult as well as in young animals).
Microglial cells from a freshly enucleated eye following trauma.
Phagocytosis of fatty droplets by microglia.
'Cooperative' manipulation of a fatty 'ball' by microgliocytes. This closely simulates a basketball game and leads, eventually, to the engulfing of the fatty globule and its digestion by one of the 'players.'
Lymphocytes in association with microglia.
The gelated, cytoplasmic 'tail' characteristic of lymphocytes.
Pigments (of a melanomatous tumor) picked up by microglia.
A neurone from the basal ganglia, showing outline of cell body

nucleus (relatively clear)
nucleolus (relatively dense)
spherical mitochondrial granules in the juxtanuclear zone
Nerve cell fibers
Regenerating nerve cell fibers, showing
'growth cones'
axoplasm
filamentous mitochondrium moving within the nerve fiber
fragmentation of mitochondria due to photosensitivity
filopodia, thread-like processes of axoplasm, seen as 'exploring' extensions of the growth cone.
mitochondria within growth cones
growth cone by-passing an axon barrier
Neurone from peripheral nervous system (dorsal root ganglion of spinal cord) showing
cell outline
nucleus
nucleolus
revolution(s) of nucleus (especially conspicuous during regenerative processes of the nerve fiber)
neurofibrils
mitochondria
satellite cells (oligodendrogliocytes)
axone
pinocytosis
vacuole formation
Schwann cells (outermost sheath cells of nerve fibers presumed responsible, in part at least, for the laying down of the myelin sheath)
The regenerated myelin sheath 'wrapping' around a single nerve fiber]

One of the recent findings of electron microscopists is that the brain in its natural state is nearly solidly packed with cellular material. There is very little intercellular substance -- probably not more than 90 Angstrom units -- between cells.

Dr. Tasaki, using stimulating and recording electrodes and a cathode ray oscillograph to study astrocytic physiology in our laboratory, demonstrated that these cells fire about 1,000 times more slowly than do neurones. Believing that these glial events are responsible for the slow waves commonly seen in electroencephalography, he has recently returned to a study of the cortical surface of the intact cat's brain.

For some ten years now we have been studying the rhythmic contractions of glial cells in our laboratory. As yet, we do not know precisely what they signify. There is, however, a strong suggestion that they effect a compression and/or massaging of other elements (including the neurones) and that such may move nutrients from one area to another.

Following severance of a peripheral nerve, e.g., the ulnar nerve in the arm, the sufferer loses control of certain important muscles in the forearm and hand. If the ends of the nerve are surgically brought together and if all goes well elsewise the neural elements within that portion of the peripheral nerve distal to the cut undergo degeneration. This permits regeneration of the nerve elements from the portion of the nerve central to the cut. In time, nerve fibers grow back into the muscle in consequence of the combined activities of filopodia, growth cones, axoplasm, mitochondria, etc. Muscle control thus returns and paralysis clears up.

Figure 10

Much remains to be learned about the conditions that deter and enhance this regeneration of nerves. The technic we have been using, including the time-numbering system, clearly opens up a number of possibilities for studying regeneration figures. Obviously, we can add to the culture medium substances suspected of stimulating the growth of nerve fibers and determine empirically whether the repair process is enhanced or not; and, if so, how much. The relationship between increased nuclear rotation and regeneration can also be explored by the same technic.

Similar possibilities are opened up in the study of the mechanics by which the myelin sheath is laid down, both initially and during repair following damage.

The process of the laying down in vitro of the myelin sheath of peripheral nerves as revealed by tissue culture studies was first described by Dr. Margaret Murray and Mrs. Edith Peterson of Columbia's College of Physicians and Surgeons. The analogue of this in vitro process occurring upon neuronal processes of the central nervous system was first described by Dr. Walther Hild. The way now lies open to study under controlled conditions

the neurological diseases characterized by demyelinization, e.g., multiple sclerosis.

We cannot overemphasize the importance of correlating the static description of the elements of the nervous system -- an extraordinarily important story spun by histological technics which depend heavily upon metallic 'staining,' especially 'silver-plating,' methods -- with the dynamic description made possible by the newer methods I have been describing. Both are needed. A pertinent example may be found in Ramon y Cajal's celebrated drawing of a typical nerve cell and its attendant oligodendroglial satellites. For every nubbin depicted by Cajal on the drawing of a nerve fiber (which had to be killed, fixed and treated with silver before being studied), we believe it proper (from our studies of living systems) to depict an extensive membrane.

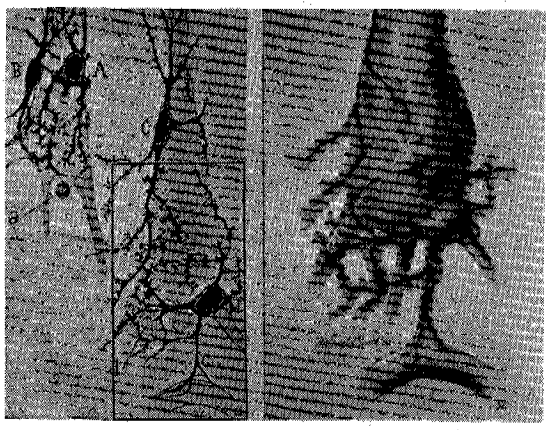

Figure 11

We have referred frequently to the rhythmic movements, the expansions and contractions of the region around the nucleus, which characterize the activity of glial cells. Such changes are, of course, reflected as changes in the diameters of the processes. By photographic printing of individual film frames, it is possible to analyze such events. Figure 12 summarizes some of these observations.

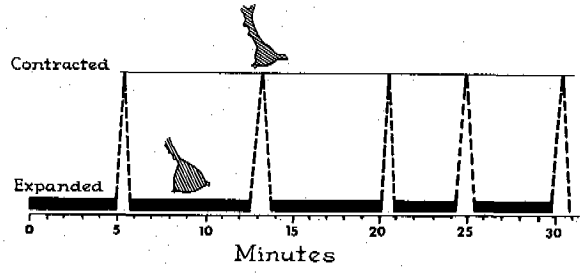

Figure 12

Let us consider, now, an instrument we devised some years ago for altering the biochemical environments of our cells (Figure 13). This consists essentially of a metal frame on the under side of which a

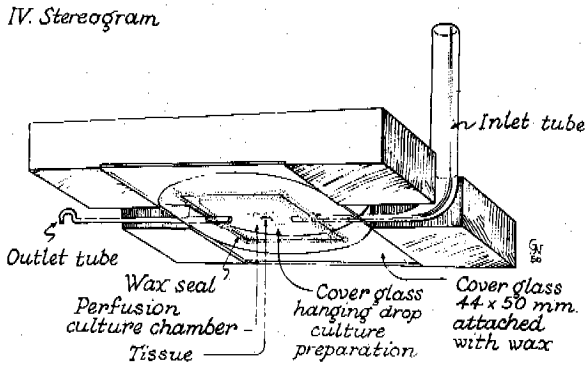

Figure 13

large cover glass is attached. Inlet and outlet tubes are appropriately affixed, thus permitting us to pass nutrients through a group of cells under focus. At a preordained moment we can add any desired drug and observe how this changes the activity of the cells. Such is manifestly a powerful tool for studying brain physiology. The influences exerted by the familiar tranquilizer, chlorpromazine, upon the rate of contraction and expansion of oligodendroglial cells are depicted in Figure 14, in which the maximal rate

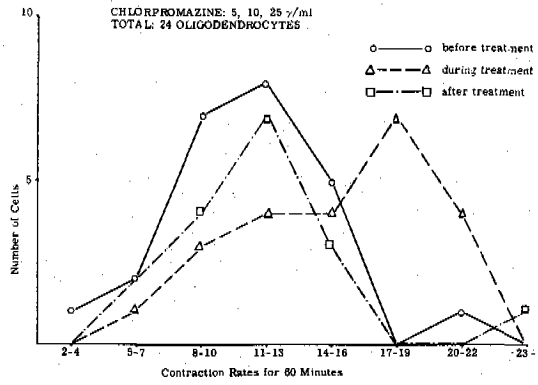

Figure 14

observed before administration of the drug can readily be seen to have been exceeded during 'treatment.' After the effect of the drug passes off, the rate of contraction and expansion returns to the original value.

In similar fashion, a wide variety of chemical substances can be used to reach a better understanding of agents being used by clinical neurologists and psychiatrists.

Another one of the very useful means of culturing cells consists essentially of a sandwich-like container (Figure 15). Between the two stainless steel plates is a rubber or silicone gasket. Thin cover glasses are placed on both sides of the gasket. The cells are

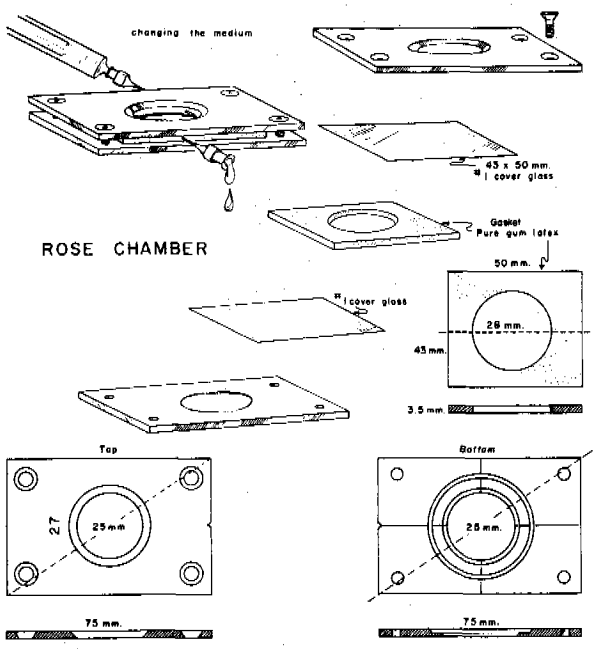

Figure 15

grown in the circular chamber which results from this arrangement. When we desire to change the medium we simply swab the presenting surface of the gasket with alcohol (much as the physician about to inject some medicinal agent prepares the skin of his patient) and stick a needle through its wall. The fluid within the chamber is withdrawn and the medium replenished. The surface view of such a chamber is seen in Figure 16. This was developed by one of our former under-

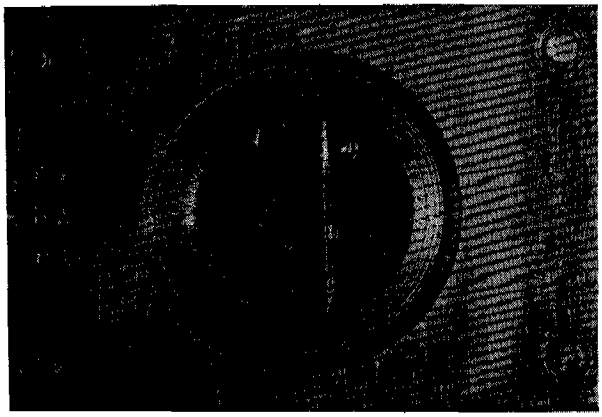

Figure 16

graduate medical students, Dr. George Rose, who has subsequently added a new and valuable modification. The latter involves placing a dialysis membrane over a piece of tissue to hold it in place. The membrane so used has a known degree of porosity. The growth pattern of tissues (e.g., striated muscles; nerve cells from dorsal root ganglia) under the dialysis membrane is perceptibly different than that seen without it. I have just reported at the Tissue Culture Association meetings in Atlantic City that we currently believe there is a reduction of diffusion of metabolic products under the membrane such that the differentiation of cells is favored. Many new challenges inhere in this disclosure.

The concluding moving picture film deals with the effect of x-radiation on nerve cells. This refers to an area of research that we consider to be most engrossing. It happens also to provide us with a useful bridge between the presentations of Professors Fry and Van Allen and the topics of my own offering this afternoon.

[The third film consisted of a number of sequences at magnifications comparable to those of the previous films in which the following structural and functional features were identified and commented upon by Dr. Pomerat:

A 'normal' control culture of neurons, glia and microglia during the 14th day of incubation.

An experimental ('sister') culture of neurons, glia and microglia on the 14th day. This culture had been exposed seven days previously to 750 r of gamma radiation. In general, it revealed the accumulation of a great deal of debris which had not been cleared away as it should have been by the microglia. Presumably, the scavenging propensities of the microglia had been reduced by the x-radiation. Moreover, the neurons of the culture were inordinately free of their usually attending elements, the glia. There obviously remained some capacity for cell division of the glial cells, as exemplified in one or two instances, but it was clear that both the glia and the microglia had suffered considerable injury.

An experimental ('sister') culture of neurons, glia and microglia as seen one day after exposure to 10,000 r gamma radiation. Radiation injury was apparent in the less differentiated cells which divide rapidly. The neurons, like striated muscle cells, exemplify highly differentiated elements. They exhibit virtually no capacity for cellular division and are, comparatively speaking, highly radio-resistant. The neurons in this cul-

ture appeared normal. After 21 days nerve cells, though damaged, remained as the only viable elements.]

Among the most sensitive cells of the body are those of the bone marrow. When compromised by x-radiation, the marrow cells fail profoundly in their role as replenishers of depleted blood corpuscles. The death of the organism may result from such failure. Other examples of highly sensitive cells are the epithelial linings of the gut and its derivatives.

In a study of intact monkeys carried out by Dr. Webb Haymaker of the Armed Forces Institute of Pathology, the Purkinje cells of the cerebellum proved most resistant to x-radiation. Their resistance broke down only when x-radiation was such as to produce leaking of blood from those vessels upon the integrity of which the Purkinje cells depend for nourishment.

By the use of tissue culture methods, the factor just alluded to, that of nutritional failure, can be obviated as a bothersome variable imposing itself upon experiments on the effects of x-radiation of different cells. In general, these methods permit us to eliminate those factors arising from systems involving the organism as a whole. They allow us to study functional elements in relative isolation and thus to explore the phenomenon of radio resistance even to cosmic rays.

I fear that I have given you a very inadequate synopsis of the vast subject of cell dynamics as revealed by tissue culture studies. But perhaps some notions of use have been conveyed to you and perhaps some tie-ups among the thoughts expressed today by Professors Fry, Van Allen and myself will have become apparent.

I should like to close by quoting Dr. James Killian who recently said, 'The future of the United States is in the hands of those who probe the mysteries of the atom, the cell and the stars.'

SYNTHETIC MEDIUM No. 858 -- PARKER AND HEALY 1955

	Milligrams per 1000 ml.		Milligrams per 1000 ml.
AMINO-ACIDS		LIPID SOURCES	
L-Arginine	70.0	Tween 80* (oleic acid)	5.0
L-Histidine	20.0	Cholesterol	0.2
L-Lysine	70.0		
L-Tyrosine	40.0	NUCLEIC ACID DERIVATIVES	
L-Tryptophan	20.0	Adenine deoxyriboside	10.0
L-Phenylalanine	50.0	Guanine deoxyriboside	10.0
L-Cystine	20.0	Cytosine deoxyriboside	10.0
L-Methionine	30.0	5-Methylcytidine	0.1
L-Serine	50.0	Thymidine	10.0
L-Threonine	60.0		
L-Leucine	120.0	MISCELLANEOUS	
L-Isoleucine	40.0	Sodium acetate	50.0
L-Valine	50.0	D-Glucuronic acid	3.6
L-Glutamic acid	150.0	L-Glutamine	100.0
L-Aspartic acid	60.0	D-Glucose	1,000.0
L-Alanine	50.0	Phenol red (pH indicator)	20.0
L-Proline	40.0	Ethanol (as an initial solvent for fat-soluble constituents)	16.0
L-Hydroxyproline	10.0		
Glycine	50.0		
L-Cysteine	260.0	ANTIBIOTICS	
		Sodium penicillin G (added just before use)	1.0
VITAMINS		Dihydrostreptomycin sulphate	100.0
Pyridoxine	0.025	n-Butyl parahydroxybenzoate	0.2
Pyridoxal	0.025		
Biotin	0.01		
Folic acid	0.01	INORGANIC SALTS	
Choline	0.50	NaCl	6,800.0
Inositol	0.05	KCl	400.0
p-Aminobenzoic acid	0.05	$CaCl_2$	200.0
Vitamin A	0.10	$MgSO_4.7H_2O$	200.0
Ascorbic acid (Vit. C)	50.00	$NaH_2PO_4.H_2O$	140.0
Calciferol (Vit. D)	0.10	$NaHCO_3$	2,200.0
α-Tocopherol phosphate (Vit. E)	0.01	Fe, as $Fe(NO_3)_3$	0.1
Menadione (Vit. K)	0.01		
COENZYMES			
DPN (95 percent pure)	7.0		
TPN (80 percent pure)	1.0		
CoA (75 percent pure)	2.5		
TPP (88 percent pure)	1.0		
FAD (60 percent pure)	1.0		
UTP (90 percent pure)	1.0		
Glutathione (100 percent pure)	10.0		

*Aqueous Tween 80 also serves as the final diluent of an alcoholic stock solution of fat-soluble constituents.

ULTRASOUND: ITS ROLES IN BASIC AND APPLIED NEUROLOGIC AND PSYCHOLOGIC RESEARCH

William J. Fry
Biophysical Research Laboratory
University of Illinois

Before discussing some of the specific roles which ultrasound can play in the investigation of basic brain mechanisms and their relations to neurological, physiological and behavioral ('psychological') manifestations of experimental animals and humans, it is desirable to consider some of the ways in which the brain is or might be organized and operated.

It is, of course, assumed in all of the following discussion that the operation of brains can be expressed in terms of a configuration or set of temporal-spatial events. The first type of brain organization which we will consider is one in which the temporal and spatial aspects of the set of events are 'separable'. This term is used to indicate that one can describe the spatial organization of the system and its temporal operation independently. At the present state of knowledge the description of a neural or brain organization is a transactional function of the specific stimuli which bear upon the animal in addition to the topological and temporal variables. Thus, the organization of parts of the central nervous system may be separable in the sense used here for some arrays of stimuli or environmental factors but not for others. In a separable organization, the destruction, disturbance or stimulation of specific sites in the brain results in the same neurological and physiological manifestations when the array of stimuli or environmental factors is repeated. At the present time it is necessary, in order to make progress toward an understanding of basic mechanisms, to restrict our inquiry to those phenomena which can be observed in a series of animals. This is a result of the fact that present experimental techniques do not permit any but the simplest mechanisms to be worked out on a single animal. Separable neural organizations can be elucidated by studying the geometric or topologic features of the organization first (Fig. 1) and then investigating the temporal organization of the structures as they respond to the array of stimuli. The temporal aspects are determined by observing the time sequence of events which occurs at different geometric sites in these brain structures.

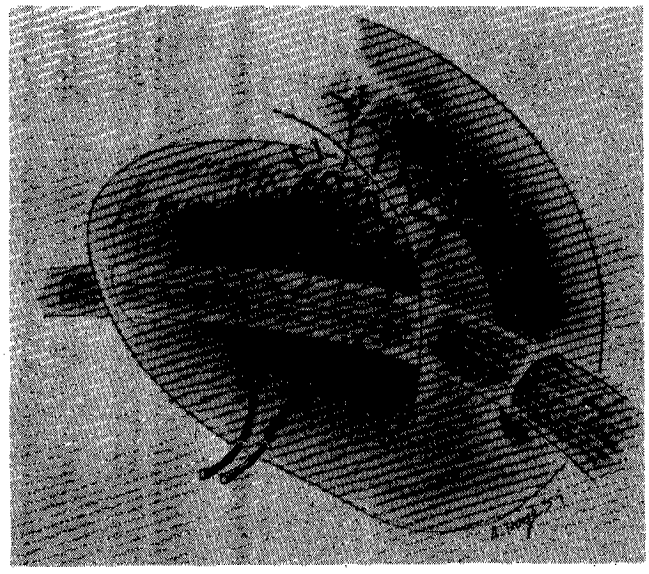

Figure 1 -- Schematic representation of a macroscopic 'separable' brain organization. The particular geometric subdivision is a function of the specific test configuration and/or method of observation. The 'twigs' represent blood vessels.

Most of the experimental work accomplished on basic brain mechanisms up to the present time has been concerned with separable organizations. For example, a specific portion of the brain is destroyed in a series of experimental animals and changes in physiological function and/or behavior are observed. The underlying mechanism is presumed to be at least partially elucidated by correlating the specific regions destroyed with the observed invariant changes and by determining the anatomical connections interrelating these regions with other parts of the brain. An example of a separable organization is the motor cortex with respect to electrical stimulation of specific sites and corresponding movement of specific muscle groups.

A 'non-separable' organization of brain structures is defined as one in which the structures do not operate in the same way in responding to the successive individual members of a sequence of test configurations or stimuli. For such an organization the destruction of a specific brain structure does not result in the same effect at all stages during a repetitive test sequence. Also, the temporal pattern of events occurring in a specific structure in response to the test stimulus or configuration is not invariant with respect to the test configuration. This latter type of organization of neural structures appears to be necessary for complex behavior, e.g., the ability to learn, forget, modify, etc.

At the present time, the investigation of a non-separable temporal-spatial organization entails setting up, in a series of animals, an initial state so similar from animal to animal that a sequence of temporal-spatial events resulting from the repetitive application of the test configuration will be reproducible. This is essential since sequences of phenomena which are different for every animal investigated cannot contribute extensively to the elucidation of basic brain mechanisms, at least at the present time.

The investigation of non-separable temporal-spatial organizations has been initiated by some investigators but relatively few results are available at present because these studies are more complicated to pursue than those in which the temporal and spatial events can be studied separately and it is to be expected that investigations of the simpler type of organization would be pursued first.

A specific example of a non-separable temporal-spatial organization which has received some attention is the investigation of the electrical activity which occurs in single nerve cells of the motor cortex following the advent of an acoustic tone which initially arouses an animal from sleep but which, if repeated a number of times, tends to arouse the animal to a lesser and lesser extent and ultimately does not result in arousal at all. If the electrical activity of individual nerve cells is recorded during such a repetitive sequence of acoustical events, one finds that the responses manifested by the individual cells to a specific event change with the temporal position of the event in the chronological sequence. That is, the activity in a specific cell, which occurs as a result of the acoustic 'stimulus', is not invariant with respect to the test configuration but is dependent upon the previous history of configurations to which the animal has been subjected, that is, upon the temporal distribution of the preceding members of the sequence.

It is, of course, to be expected that combinations of separable and non-separable brain mechanisms exist. In fact, a specific brain structure may exhibit a 'separable' organization with respect to a particular test configuration and a specific type of measurement of its activity and a 'non-separable' organization with respect to other test configurations and/or measurements of activity.

In studying brain mechanisms it is necessary to consider the magnitudes of both the spatial and temporal scales upon which the operations of the system and its components are organized. Such considerations are important since the choice of experimental technique to be employed depends in general upon these 'scales' of organization. For example, the operations of elements of a structure of the system closely adjacent to one another geometrically might resemble each other and gradation in type of operation might occur on a macroscopic scale (Fig. 1). An example of such an organization is the motor cortex with respect to the eliciting of motor movement in response to electrical stimuli at specific sites in the cortex. The cortex is organized with respect to this test configuration and manifested motor activity so that movements in different muscle groups of the body are topologically represented on a gross or macroscopic spatial scale. That is, the 'center' of the cortical region in which hand and finger movements are most readily elicited is separated by a distance of the order of a few centimeters (in the human) from the region in which leg movements are elicited. Microspatial organizations of brain structures, with respect to specific test configurations, also exist (Fig. 2). In such an organization at least some of the neighboring elements of a structure, which lie within microscopic distances of one another, exhibit completely different types of activity in response to the given test configuration. No gross subdivision of the geometric structure may be possible, with respect to the given test configuration and the type of measurements or observations made, and the microscopic elements cannot be classed in a single group on the basis of their operation. Relatively little work has been accomplished in this direction, as compared to the work on the investigation of macrospatial organizations, but microelectrode methods have begun to shed some light on organization on the microscale.

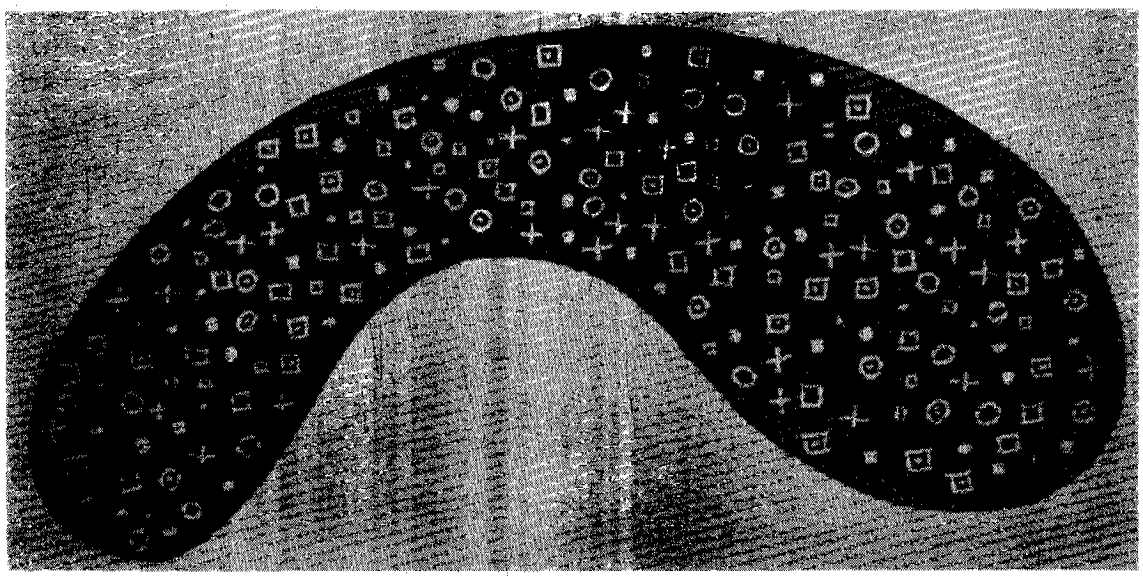

Figure 2 -- Schematic representation of a microspatial 'separable' brain organization. The classifications into which the microelements are separated are a function of the specific test configuration.

Investigation of temporally separated events can be considered on the basis of the duration of the time intervals involved. At the short end of the time scale are sequences of events which occur within times of the order of a few to possibly a hundred milliseconds, that is, from a few thousandths of a second to 0.1 second. (The term 'microtemporal' is used here to refer to such sequences.) Such time durations span sufficiently long periods to include 'complete-sequences' of activity of some neural pathways involving only a few elements, e.g., the operation of the pathway from the motor cortex through the corticospinal tracts to the motor nerve cells of the ventral horn of the spinal cord to the motor endplates of the muscles. A considerable amount of experimental work has been accomplished on the study of sequences of electrical events which transpire in neuron groups which participate in 'microtemporal' mechanisms.

By contrast with the temporal events which occur in a few milliseconds to a hundred milliseconds the brain exhibits long-term 'integrated' behavior. Although many observations have been made on such behavior and much attention has been given to its study by psychologists, sociologists and others, there has been very little progress in the understanding of basic mechanisms, that is, explaining such behavior in terms of events taking place in individual nerve cells or groups of such cells in brain structures.

With these preliminary remarks in mind we now consider the question, 'How can the brain be investigated both from the viewpoint of obtaining a basic understanding of the "observed" manifestations of its operation and from the viewpoint of inducing desired changes in its operation?'

Various methods have been devised for studying and inducing changes in brain mechanisms. In order to understand the advantages and the new possibilities which ultrasound offers we will show how the older techniques and methods are limited in their ability to elucidate the various types of brain organizations already briefly described. We will then indicate how ultrasonic methods, used alone and in conjunction with other existing procedures, can contribute additional knowledge to an understanding of such organizations. Ultrasonic procedures already in use will be discussed and, in addition, speculation on future advances to be expected from further investigation of the action of ultrasound on brain components under a wide variety of conditions will be presented. The present advantages and potential of ultrasonic methods in applied neurological and psychological work on humans also will be summarized.

Consider first separable, macrospatial brain organizations. As already defined, the spatial and temporal features of such an organization can be described independently of each other and the spatial scale of organization is not microscopic with respect to the test configurations and the observed responses (Fig. 1). One of the methods which has been extensively employed in investigations of such brain organizations is that of destroying a portion of it and then studying the experimental animal for changes in behavior or other activity (control of internal environment, etc.). Observations and measurements are made on the animals before the specific portion is

destroyed and, in much behavior work, the animal may undergo a program of training before the lesions are made. After completion of the work on the whole animal the brain is removed and prepared for study under the microscope to determine the precise location and shape of the lesions and to trace to their destinations the pathways of nerve fibers which originated in or traversed the regions destroyed. Although the procedure of destroying a region has yielded a great deal of information, it has suffered from a number of serious drawbacks. Some of these are the result of the assumptions which have been and still are sometimes made in drawing conclusions from data obtained from such studies. Others are the result of the methods which have been used to produce the destruction of the tissue. And a third category of difficulty has been the result of the unavailability, up until recently, of a good method of selectively staining 'all' (a large fraction) degenerating nerve fibers which leave a destroyed region.

We consider first the difficulties associated with the methods used to destroy the tissue. The earliest methods were mechanical in nature. They involve the use of cutting instruments or devices to remove tissue by suction. Chemical agents are introduced into regions of the brain by means of hollow tubes which are pushed through the tissue to bring the opening to the desired site. Electrodes to coagulate or otherwise destroy nerve tissue are placed at a desired site by penetrating the intervening tissue with a thin cylinder which carries the electrodes at its tip (Fig. 3). These older methods result in the destruction of tissue intervening between the

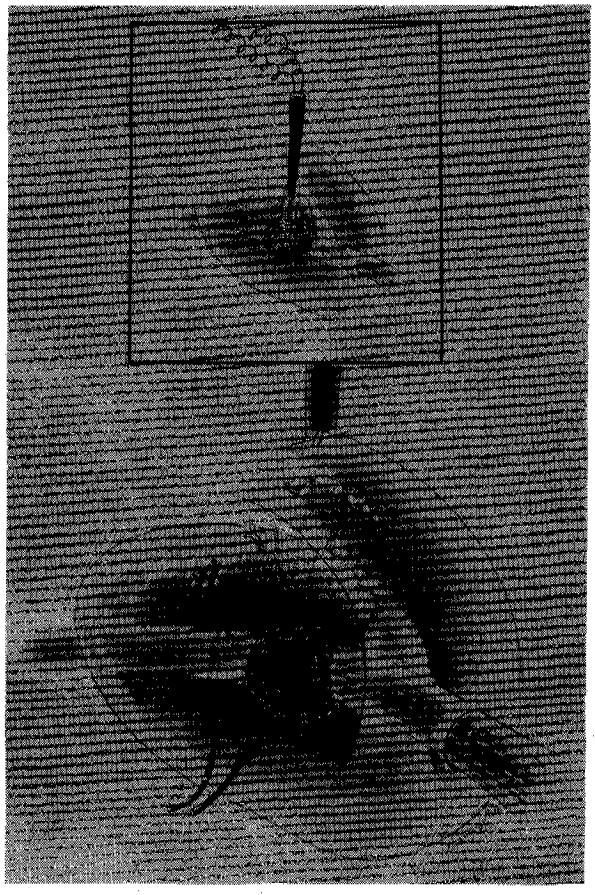

Figure 3 -- Destruction of a portion of a macroscopic brain organization by electrocoagulation represented schematically. (The intact organization is represented in Fig. 1.) The penetrating cylinder, which supports the electrodes, destroys intervening tissue and it is clear that the central region can be completely destroyed only by employing multiple penetrations. The interruption of the twig structures illustrates the fact that blood vessels in the affected region are destroyed.

region destroyed and the surface of the brain. As a result, the effects obtained cannot in many cases be unambiguously ascribed to the destruction of the tissue at the desired site since the destruction of the penetrated tissue may be of equal or greater importance in producing the observed changes. In addition to possible complications resulting from the destruction of intervening tissue, these older procedures are not capable of being used to selectively destroy specific tissue components in the region to be affected -- that is, all types of tissue or cells in the region are destroyed. This includes the blood vessels. Difficulties then result from the fact that a hemorrhage may occur or that interrupted blood vessels may supply regions of the brain not within the site to be destroyed. Interruption of such blood vessels can result in the dysfunction of nerve tissue components other than those encompassed in the region of the primary lesion (region of destruction).

The necessity of introducing a mechanical device in order to reach the region of interest has made it impractical and in many cases impossible, to produce lesions of particularly desired shapes to correspond to the forms of specific nuclei or nerve fiber tracts. (This is illustrated in Fig. 3.) Each time a tube or rod is introduced intervening tissue is destroyed so that if a region of complex shape or of relatively large size is to be affected more tissue may be destroyed outside the region of interest than within the region. Consequently the number of times a mechanical device is inserted is usually restricted to one or two penetrations to destroy any specific region. This is the case for both experimental animals and for humans (neurosurgery of deep brain structures).

Another approach to the study of brain organization, not involving the mechanical penetration of brain tissue, employs the vascular system to carry chemical agents into the brain. Such chemical procedures are useful in experimental animal studies and in applied neurology. However, they suffer, if used alone, from a major difficulty from the viewpoint of elucidating basic brain mechanisms. That is, it is difficult to find chemical agents which can selectively affect specific brain regions and if such a selective action exists it is difficult to identify it. Other agents which have been used to destroy tissue in the central nervous system are X-ray radiation and high energy nuclear particles. These two methods suffer from the disadvantage that radiation damage is produced in all intervening tissue in the path of the beams and that the effects of such damage are accumulative. In addition, no range of dosages for producing destruction of neural tissue without some interference with the vascular system has yet been demonstrated and there is no evidence indicating that reversible changes can be induced in nerve tissue components. The advantage of these latter two methods over the use of mechanical devices is that a surgical procedure requiring penetration of brain tissue to the sites of interest is not required.

Essentially all of the disadvantages of the methods just discussed are eliminated by using precisely controlled focussed high intensity ultrasound for producing changes in deep brain structures. And in addition, ultrasonic procedures make possible methods of attack on problems of brain organization based on principles which could not be entertained with other methods. The only disadvantage apparent in the ultrasonic procedures at the present time is that a portion of the skull bone must be removed to permit the sound to enter the brain. However, irradiation can be accomplished through the skin if a window has been made in the bone so that treatment need not be performed at, nor confined to, the time the bone is removed. The frequency of the ultrasound employed in this work is 1,000,000 cycles/sec. which is considerably above the audible pitch limit of human hearing. Ultrasound at this frequency can be focussed by relatively small lenses or reflectors to produce small focal regions. It is thus possible to affect small volumes of tissue in the brain, or by placement of the focus at a number of positions to irradiate practically any desired volume of tissue. One type of focussing irradiator, which we have used extensively, is illustrated schematically in Fig. 4. The sound is produced by four vibrating crystal plates of circular cross section, each caused to vibrate at its resonant frequency by electrical means. Each crystal plate is provided with a lens for focussing the sound. The acoustic intensity is greatly increased over that of the individual focussed beams in the region of their intersection, and it is only in this region that changes in the tissue are produced. Figure 5 is a photographic illustration of one of these four beam irradiators.

Since the ultrasound can be focussed, and at low dosages does not produce damage to brain tissue, it is possible to irradiate and destroy tissue at any desired depth in the brain without any deleterious effects on intervening tissue. The focal spot of the sound beam(s) can be moved about in the brain to cover the desired 'shaped' volume. This is illustrated schematically in Fig. 6 which shows a configuration of structures, the neural components of one having been chosen for destruction.

As the frequency or pitch of the ultrasound is increased the minimum size of the focal region which can be obtained is decreased so that at higher frequencies it is possible to destroy tissue components in smaller volumes of brain. (At a frequency of 4 million cycles/sec. it is readily possible to restrict the volume of tissue affected to considerably less than one cubic millimeter.) However, one cannot increase the frequency indefinitely since the absorption of the sound in the intervening tissue increases with the frequency. Therefore, it is necessary to choose the frequency to be employed in a specific study or application on the basis of both the fraction of the incident acoustic energy which would be absorbed in the intervening tissue and on the smallness of the focal spot size desired.

In addition to the elimination of adverse effects on intervening tissue, ultrasound can be used, under appropriately chosen dosage conditions, to produce selective changes in the tissue components in the region affected. The blood vessels of the brain are the most resistant elements to the action of the sound and consequently it is possible to destroy all of the nerve components in a given region without interrupting the vascular system in the same site. (This is illustrated schematically in Fig. 6.) This eliminates difficulties associated with the other methods, caused by interruption of blood flow with possible consequent changes in tissue other than that in the desired site.

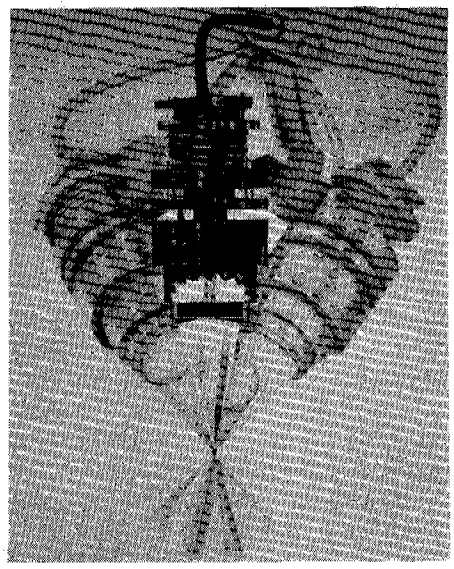

Figure 4 -- Schematic diagram of a four beam focussing irradiator. The housings, which support the individual crystals, are provided with adjustments which permit the individual beams to be brought into coincidence. The irradiator is also provided with a retractable pointer whose tip can be placed at the common focus of the beams. This pointer is useful in positioning the focal region of the irradiator at desired geometric sites in the brain.

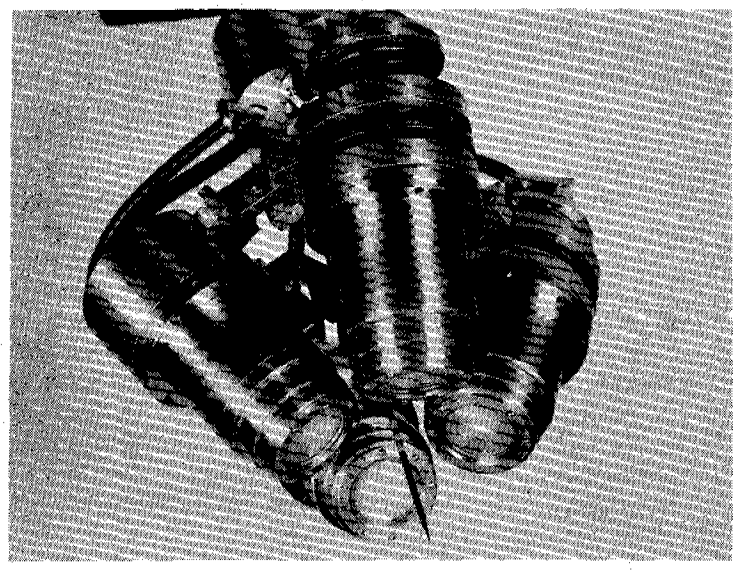

Figure 5 -- Photographic illustration of four beam focussing irradiator. See Fig. 4 for a schematic diagram of this device.

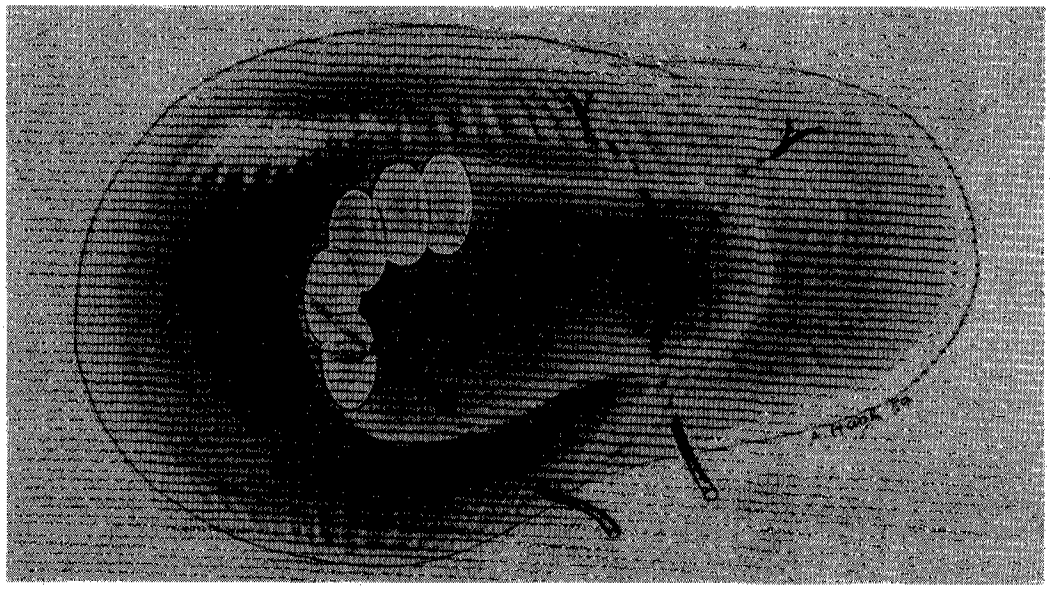

Figure 6 -- Schematic diagram illustrating the destruction by focussed ultrasound of a macroscopic deep brain structure. The focal region of the ultrasonic beams is moved from one position to another in order to 'cover' the desired volume. The destruction of all nerve components of the brain structure is accomplished without adverse affect on intervening tissue and without disruption of the blood vessels within the structure in which all the nerve elements are destroyed.

In addition to the selective sparing of the blood vessels it is possible, by appropriate choice of ultrasonic dosage conditions, to destroy the nerve fiber tracts of the white matter (regions containing nerve fiber bundles but 'no' nerve cell bodies) of the brain without disrupting immediately adjacent gray matter (regions containing the nerve cell bodies), which receives the same dosage of ultrasound. This selective action, realized over a specific dosage range, makes it possible to destroy complex shaped fiber tract regions without damaging nuclear masses. Figure 7 illustrates schematically the selective destruction of nerve fiber tracts of white matter with no irreversible effects on neighboring gray matter and no interruption of the vascular system. Such a selective destruction of the nerve fibers of the brain is illustrated by the shaped lesion in the next figure which shows a stained brain tissue section from a cat (Fig. 8). It was produced in the fiber tracts just below the cortex of the brain by moving the focal spot of the sound beam successively from one position to another as illustrated schematically in the previous slide. Close scrutiny under the microscope of the boundary region between the gray matter and the affected white matter shows that the nerve cells of the gray matter adjacent to the boundary are essentially undamaged (Fig. 9). Since the ultrasonic focussing method is particularly suited to the production of lesions of complex shapes and any desired sizes, it is visualized that particularly useful ones will be those in the form of curved sheets oriented to separate various nuclear masses of the brain from one another (Fig. 10). Such lesions are completely impractical to produce by the older methods employing mechanical devices to reach the region of interest. Lesions of this form would permit the nerve cells whose fibers do not cross the boundary of interruption between the nuclear masses to remain intact and functioning while those cells giving rise to fibers traversing the boundary would be affected. Therefore investigations employing lesions of this type could be expected to yield information which could not be obtained from studies employing the complete destruction of the individual nuclear masses. Investigations employing sheet lesions are thus expected to contribute extensively to the further understanding of macrospatial brain organizations.

The term 'diffuse' is used in describing the anatomy of some parts of the brain -- the nerve fibers present in such regions run in a variety of directions and it is not possible to distinguish under the microscope any specific or definite grouping of cells. It is expected that sheet lesions would be useful in elucidating the anatomy of the diffuse systems of the brain since they could be oriented in different directions, in different experimental animals, at a particular anatomical site. Thin, curved sheet lesions, with areal dimensions of the sheet relatively large compared to the thickness, would be useful in elucidating the pathways and terminations of fibers running in different directions. The anatomy of diffuse systems cannot be attacked in a very practical way by the methods of lesion-making using mechano-chemical or mechano-electrical means since the shapes of the regions destroyed are more or less spherical and in addition the vascular system is interrupted.

Ultrasonic methods also provide the possibility of producing reversible changes in tissue components of the central nervous system. This makes it possible to produce, at localized and specific sites, changes in the mechanism of operation of the system from which the system recovers. None of the other methods of inducing changes in brain tissue permit this to be accomplished if the site of the desired action is to be movable from one position to another. Before discussing in more detail the reversible type changes which ultrasound can produce in the central nervous system I would like to comment briefly on assumptions which sometimes have been made in interpreting data obtained from experiments involving the <u>destruction</u> of portions of the brain.

Although the lesion method of studying brain mechanisms has been fruitful it has also generated the idea, still receiving some support, that all aspects of behavior and physiological function can be identified with the operation of specific sites in the brain. The lesion method is extremely useful in tracing anatomical connections (to the sites of the first synapses) but when it is used to study brain organization and its relation to behavior and physiological function one must be extremely careful in interpreting the results. For example, the assumption is sometimes made that if a region of the brain is destroyed and a change in some aspect of behavior is exhibited by the animal, either in his 'spontaneous' activity or in response to a test configuration set up by the investigator, that the region of the brain excised or destroyed was 'directly' related to the brain mechanism involved in the maintenance of the state of the animal before the change was produced. By the term 'directly' we mean here that an examination of processes taking place in the region of the brain to be excised would show changes when the animal engages in its normal activity or responds to a test situation determined by the investigator. For example, it has been shown that a certain area of cortex, the so-called motor area, is electrically excitable, that is, motion in muscle groups results when a pulse of electric current is passed through a volume of tissue in this region. On the basis of these observations <u>alone</u> it might be assumed that the so-called motor cortex is 'directly' involved in the mechanism of muscle movement exhibited by the animal in response to environmental factors or test configurations. However, this conclusion does not follow because the mechanism of operation of a portion of the brain may be affected by the removal of another region simply because this second region normally modi-

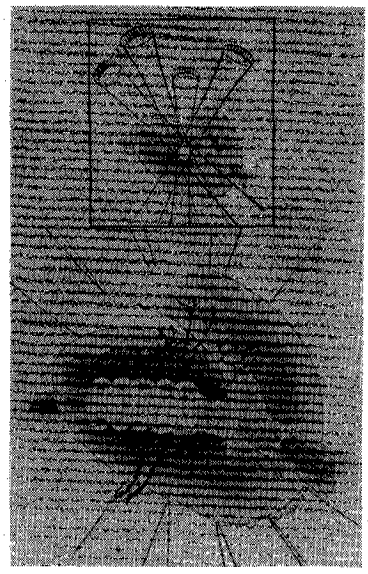

Figure 7 -- Schematic diagram illustrating the selective disruption of the fiber tracts of white matter of the brain by focussed ultrasound. The ultrasonic dosage parameters can be chosen so that gray matter, which surrounds or borders on the fiber tract region, is not disrupted even though it is subjected to the same ultrasonic dosage conditions which result in disruption of the nerve fibers of the white matter. This is illustrated in the figure by showing intact the structures which border on the region in which the common focus of the beams is successively focussed. The blood vessels in the region of destruction of the nerve fibers are also shown uninterrupted.

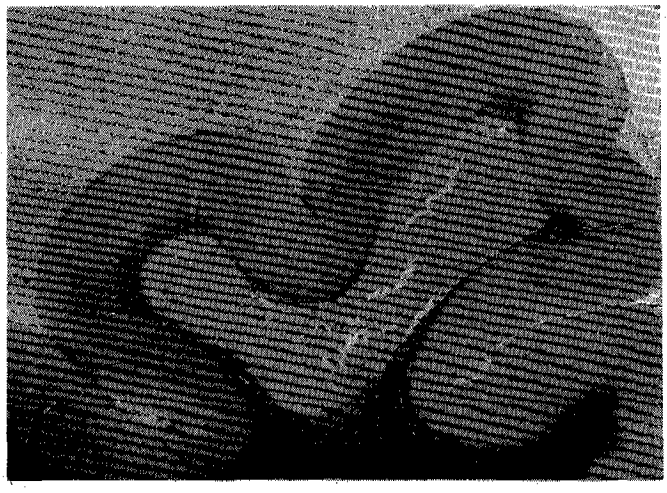

Figure 9 -- A photographic enlargement of the region of the lesion illustrated in Fig. 8. This enlargement shows that the boundary between the region of destruction and the neighboring undisrupted tissue is very sharp.

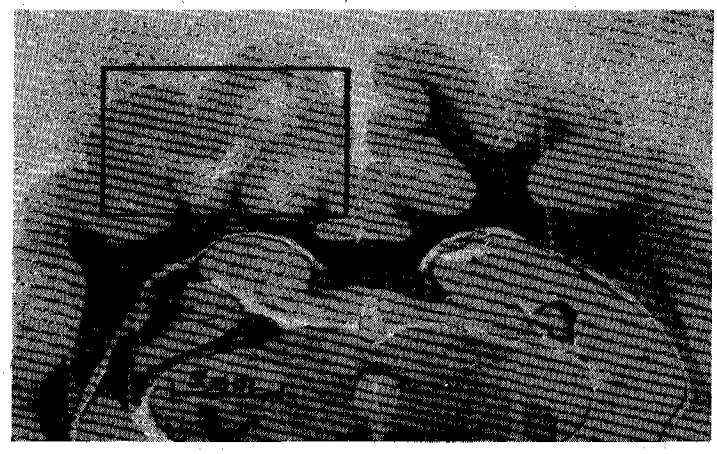

Figure 8 -- Large, shaped, selective subcortical white matter lesion in a cat brain. The figure shows a slice through the brain with the tissue stained so that the white matter or fiber tract regions appear dark. The lesion (region of destruction), which is the light area enclosed within the box, was produced by placing the common focus of the ultrasonic beams successively in a number of adjacent positions spaced a fixed distance apart (1/2 mm.).

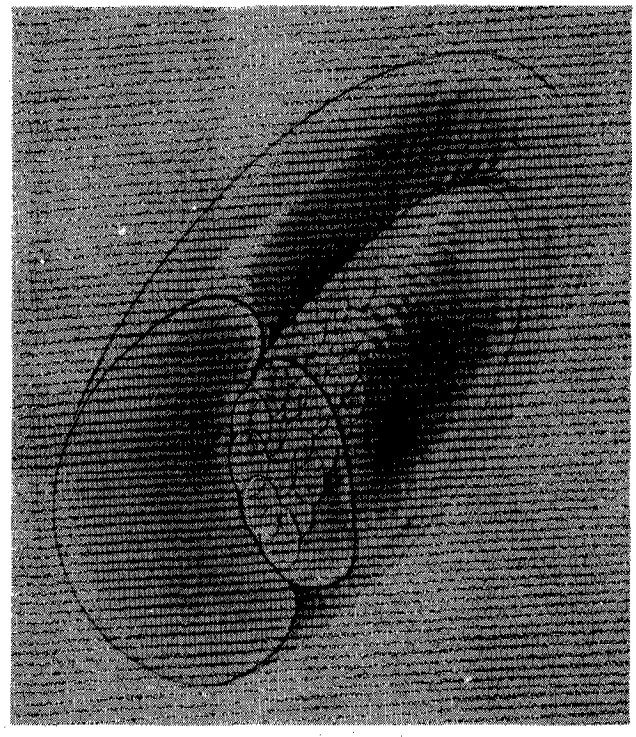

Figure 10 -- Schematic diagram illustrating the separation of two adjacent macroscopic brain structures by ultrasonic means. A series of adjacent overlapping lesions placed to conform to the boundary region of the adjacent structures accomplishes this.

fies the activity of the first and when it is removed the operation of the first is changed. Therefore it is necessary in order to determine whether a specific region is involved 'directly' in a brain mechanism to study the region by means other than destruction -- for example, the examination of the electrical events occurring in the region during the exhibition of the particular behavior under consideration might be fruitful.

Not only can one not conclude that a region is 'directly' involved in a specific mechanism because its excision induces a change, but one also cannot conclude that if a structure is removed and no change occurs, that the structure was not involved in the mechanism. It is only necessary to observe here that the brain may be organized in such a fashion that with a given test configuration the same response may be produced by the utilization of a number of different intermediate 'pathways' or mechanisms. One specific mechanism or pathway may be used until it is damaged or removed whereupon another organization or mechanism may then 'take over' and so far as the observed behavior of the animal is concerned no change has been induced. This is illustrated, for example, by the removal of the motor cortex from the brain of a cat. If one observes the cat's gait, retrieving of food and other cage activity after the removal no apparent change is seen. (It is, of course, possible to demonstrate changes in so-called placing reactions for a short time but later on even these deficits disappear and in any case we are considering a given test configuration and a specific type of behavior of the animal.) The fact that the animal shows no change in gait, etc., after removal of the tissue does not mean that there are no changes taking place, before excision, in the motor area during walking or during the observed type of cage activity. In fact, one can demonstrate by direct measurements that electrical changes take place in the nerve cells of the motor cortex when the animal is aroused and exhibits motor activity. It is necessary therefore, if one is to conclude that a specific region of the brain is 'directly' involved in the mechanism of a specific behavior, to perform, for example, electrical measurements on the region during the exhibition of such behavior.

For the study of macrospatial organizations relatively large size electrodes can be used to determine whether electrical changes occur in the region of interest during the exhibition of the activity under investigation. Of course, if no electrical change is observed, this does not imply that none occurs on a microscale but simply that the average change as sampled by macroelectrodes is zero or that the change cannot be detected above the 'spontaneous electrical background'. One must also guard against drawing unwarranted conclusions from electrical data alone -- for example, if the electrical activity exhibits a change in a region during a sequence of tests or observations, this does not imply that the particular responses or behavior under examination will undergo a change.

It is apparent that studies employing lesions and/or gross electrical measurements cannot hope to elucidate all aspects of basic brain mechanisms of even the macroscalar type. Fortunately ultrasound provides an additional tool for the investigation of such macroorganizations. Reversible changes -- that is changes which result in no permanent damage -- can, as indicated above, be induced in brain structures to modify the 'spontaneous' activity of the animal or his response to a given test configuration. Ultrasonic procedures employing dosages to induce only reversible changes (now in the early stages of investigation) will constitute an extremely powerful tool for studying brain mechanisms. Since it is possible to move the focus of the beam(s) through any desired pathway in the brain and thus to cover any desired structure, it is possible to produce three dimensional brain maps, demonstrating and elucidating brain mechanisms. The method can be used in conjunction with electrical techniques for the study of these mechanisms. For example, one might place stimulating electrodes at a number of sites in the brain of an experimental animal and electrodes for detecting electrical changes at other sites. Then by sweeping the focus of the ultrasonic beam through the brain along nerve pathways interrelating these sites, one could elucidate brain mechanisms by modifying the transfer of information from the stimulating sites to the detection sites. A study we have currently in progress on the visual system illustrates this. Flashes of light on the retina or electrical stimuli applied to the optic nerve excite the optic tract. In response to such stimuli electrodes placed on the visual cortex of the experimental animal exhibit electrical changes a short time after the initiation of a stimulus. The pattern of the electrical response at each electrode is quite complex and must mirror various aspects of brain organization. By using ultrasound at reversible dosages one can demonstrate changes in the various phases of the electrical response pattern as a function of the position of the acoustic focus in the various brain structures. One thus obtains a three dimensional map showing what brain structures bear upon or are involved in the mechanism of the production of the various phases of the evoked electrical potentials (Fig. 11). This mapping constitutes information regarding the spatial and temporal organization of the visual pathway. An extension of this type of experimental setup would make it possible to investigate the so-called 'association systems' in the central nervous system by the use of focussed ultrasound under reversible dosage conditions. (These systems are presumably involved in the task of determining the type of response which will be exhibited by the animal in a given test configuration.) The focus of the sound beam(s) would sweep through a structure or combination of structures in a

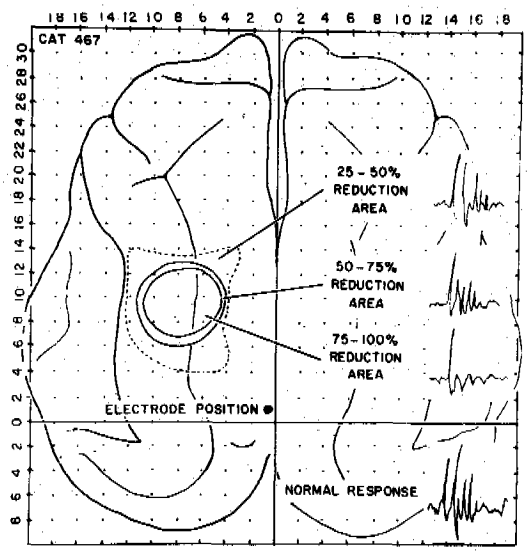

Figure 11 -- Temporary reduction by ultrasound, focussed in the region of the lateral geniculate nucleus (a station along the visual pathway from eye to cortex), of the second and subsequent peaks of the electrical potentials which can be detected in the visual cortex when an eye of the experimental animal is subjected to flashes of light. As the common focus of the ultrasonic beams is moved from one position to another in the region of this nucleus the various components of the electrical potential elicited by the light at each position in the cortex (one electrode position indicated on the figure) are affected to different extents. (Characteristic changes in the form of the potentials are shown in the series of recordings shown on the right hand side of the figure.) This is indicated by the contour mapping shown on the left side of the figure. (The cat's brain is viewed from above.) This mapping corresponds to a plane of focus of the ultrasound through the middle of the lateral geniculate nucleus. Such maps are useful in determining what specific brain structures are involved in basic mechanisms of brain operation.

variety of geometric paths while continuous testing of the experimental animal or the human is in progress. If, for example, the visual 'association system' is being investigated the testing might consist in determining the ability of the subject to perform discriminations with respect to form, brightness, color, and arrangement of visual patterns. The complete test sequence could be repeated as a particular geometric path is traversed by the acoustic focus in order to permit adequate checking of the responses of the subject. As the path of the focus is varied in position and shape, the results of the testing would be examined for any deviation from the responses preceding irradiation. When an indication of a change appeared the path traversed by the focus would be modified to enhance or otherwise affect the observed responses. Such a procedure would make it possible to obtain information on temporal-spatial configurations which exist among the neural elements to result in the observed behavior. After experience with relatively simple test configurations is obtained, more complex problems could be attacked -- visual memory with storage and recall, correlative ability involving visual patterns and cues, problem solving employing visual constructs, etc. The use of ultrasound under reversible dosage conditions in the manner proposed here can be considered as the equivalent of disturbing the temporal organization of the system in a large number of internal loci. In this sense the moving focus of the ultrasonic beam or beams would take the place of a huge number -- ten to one hundred thousand -- of electrodes excited to produce a distribution of threshold or other changes in specific brain structures. In order to accomplish the type of study just indicated, it would be necessary to elaborate the instrumentation over that available up to the present in our laboratory. The present most elaborate ultrasonic irradiation instrumentation with auxiliary equipment is illustrated in Figs. 12, 13 and 14. Figure 12 shows a schematic diagram of this instrumentation. Figure 13 shows a photograph of the irradiation room with the tube which supports the irradiator projecting through the ceiling. This tube is supported and moved about by a positioning system housed above the irradiation room. The figure shows the closed circuit television systems which permit positioning of the irradiator, the calibration instrumentation for determining dosage conditions, the holder for supporting the experimental animal, the electronic instrumentation used for recording, and stimulating and for supplying power to the irradiator. Figure 14 shows the positioning system in the room above the irradiation area. This system permits automatic and continuous sweeping of the focal spot of the beam through the brain. However, in order to accomplish both automatic sweeping and data examining sufficiently rapidly, it would be necessary to elaborate the instrumentation by employing control and data processing equipment comparable to that used in launching rocket and space satellites. Automatic processing of the data must be handled as irradiation continues and the results must be used to modify and determine the shape of the path of the focus through the brain. It is envisioned that a study of the association systems of the brain, in the manner described here, would permit considerable elucidation of the macrospatial organization both on the microtemporal and macrotemporal scales. If such is the case, it would constitute a major step toward a basic understanding of the complex behavior of the central nervous system.

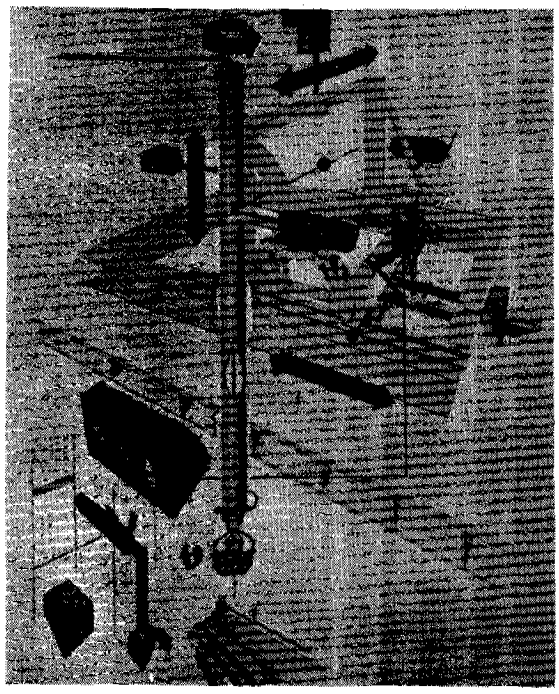

Figure 12 -- Schematic diagram of the instrumentation used to produce accurately controlled changes in the brain by focussed ultrasound. The equipment is housed in two rooms one above the other. The upper room houses the positioning system which supports and moves the irradiator. The lower room contains the supporting structure for holding the head of the animal in position, the calibrating system for setting the ultrasonic dosage parameters, control equipment for positioning and moving the focus, recording equipment for noting the responses of the animal (including electrical changes in the brain) and stimulating instruments of a variety of types. The positioning of the irradiator is facilitated by employing closed circuit television systems to view the scales on the positioning system and to provide magnified images of these scales in the irradiation room.

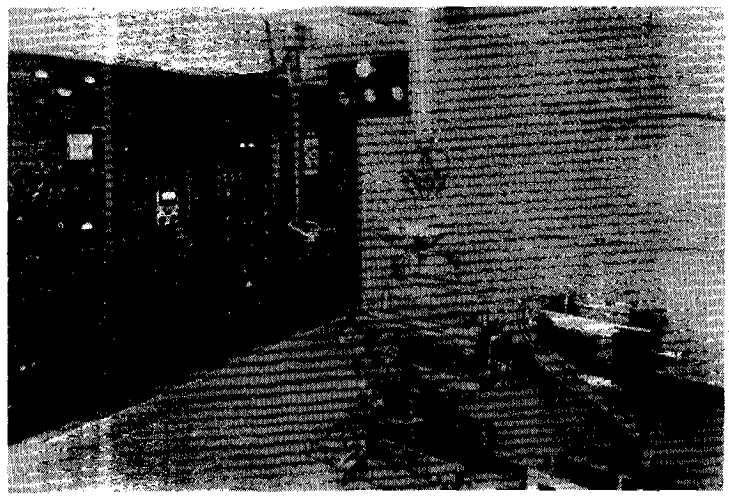

Figure 13 -- Photograph of the irradiation room showing the animal holder with a skull mounted in the apparatus. (Refer to Fig. 12.) The open-bottom hopper which ties on the opened skin of the animal and provides a support for the transmitting liquid (sterile degassed saline) is shown in position over the skull. For irradiation the four beam transducer is lowered into the saline in the hopper. The calibration tank shown to the right of the animal holder rides on a track which positions it under the irradiator. This tank supports an acoustic probe and saline bath in which the irradiator is partially submerged for determination of acoustic field characteristics and calibration purposes.

Figure 14 -- Photograph of room which houses the coordinate positioning system. (Refer to Fig. 12.)

The study and elucidation of the microspatial organization of the central nervous system presents additional difficulties. Microelectrodes can be employed in order to sample the electrical changes exhibited by individual neural elements but it is obviously impossible to employ a sufficiently large number of such electrodes to yield much of a sample of the microspatial activity in the same experimental animal. Microelectrode studies already reported have shown that portions of the brain are organized on a microscale with respect to mechanism -- that is, elements within microdistances of one another do not exhibit similar activity. Focussed ultrasound can be used to investigate microspatial organizations of the central nervous system. For this purpose, dosages of ultrasound which cause only reversible changes will be especially useful. We have already indicated that it is experimentally possible, under appropriate conditions, to induce by ultrasound changes in the components of the electrical potentials seen at a series of detecting electrodes placed in the visual cortex of the cat. Although the detailed mechanism by which the ultrasound induces the observed reversible changes is not yet known, it is probable that the changes result from shifts in synaptic excitation thresholds or in excitabilities of nerve cell bodies to stimulation by incoming signals. This view is supported by the fact that the magnitude of evoked potentials in regions far removed from the site of the focus of the sound can either be increased or decreased by appropriate choice of the irradiation conditions. The conclusion also receives support from the fact that the magnitude of the augmentation or suppression is markedly dependent upon the site of the focus of the sound -- that is, slight changes in the position of the acoustic focus, corresponding to shifts across the boundary between two internal brain structures or organizations, may result in large changes in the magnitudes of the evoked potentials. Therefore, it should be possible to investigate the distribution of synapses along a specific pathway or system even when it is imbedded in a number of other systems with components in the same geometric regions. This would appear to be the case for both compact fiber systems (readily identified bundles of fibers) and for systems in which the fibers are diffuse and scattered through regions of nerve cell bodies. Electrical methods, utilized up to the present time, are appropriate for determining the number of synapses along a pathway if this number is not too large, that is, not more than three or perhaps four. If the number becomes greater than this it is difficult to deduce the number of synapses from the total time interval between stimulation at a site and detection of a response. However, with the focussed sound method it would be possible to locate the positions of the synapses along a pathway (if they are no closer than say 0.1 mm.) in deep structures and consequently the number along the pathway could be deduced from the number and type of the changes which occur in the electrical potentials (evoked or 'spontaneous') as the focus of the beam(s) is moved through the tissue.

Another possibility, but one which is purely speculative at present and therefore should receive early attention, is that ultrasound under 'reversible' dosage conditions might selectively affect a particular sub-group of nerve cells of the total population in a specific region. That is, it may be possible with ultrasound to subdivide nerve cell populations in some brain structures into classes determined by the action of the sound.

Another purely speculative direction for research, which we plan to investigate, is the possibility that some chemical agents injected into the vascular system might be made to affect nerve elements in a given region by using focussed ultrasound to produce a change in the tissue structure which would permit the agent to exert an influence. If such chemical agents can be discovered an additional powerful procedure would be available for investigating central nervous system mechanisms.

Another possible approach to the study of brain mechanisms, both on a micro- and macroscalar basis, would employ hypothermia (reduced temperature) states to interrupt the operation of brain mechanisms and the use of focussed ultrasound to heat specific structures to operating temperatures. Since high intensity sound is absorbed quite strongly in brain tissue, a temperature increase is produced when the sound is propagated through the tissue structure. Consequently it would be feasible to ultrasonically irradiate structures which have been reduced in temperature by hypothermia means to bring them to the operating temperature range. It would appear possible to bring almost any desired combination of brain structures into an operating temperature range by this means. This proposed technique would appear to have possibilities for separating some of the maze of interrelated and modifying mechanisms brought into play when the brain carries out a sequence of operations.

Many of the methods just described would contribute to the elucidation of both the micro- and the macro-temporal aspects of separable macro- and microscalar brain mechanisms. The investigation of non-separable brain organizations poses the additional difficulty that the spatial and temporal aspects of such organizations cannot be described independently. This means that the experimental animal or human subjected to a repetition of the same test configuration will not exhibit an invariant pattern of response. Therefore, in order to obtain repeatability of data in a single animal, it would be necessary to devise auxiliary procedures to return the animal to a state so similar to the initial one that the test sequence could be repeated any number of times with similar results. At the present stage of our knowledge it may require periods of time of the order of days, weeks, or

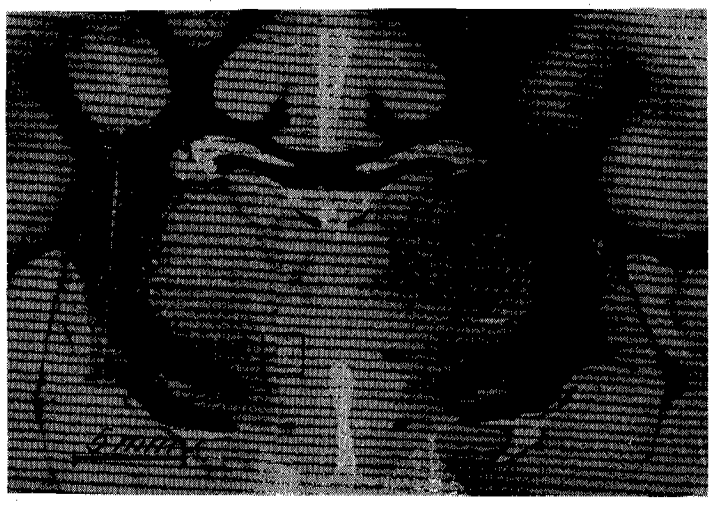

Figure 15 -- A stained tissue section from the brain of a cat showing the dark stained 'normal' mammillothalamic tract on the right and the enclosed light patch on the left where the tract was interrupted by focussed ultrasound. Although this tract is near the base of the brain and the focussed beam therefore traversed almost the entire depth of the brain there is no damage to intervening tissue.

longer for a non-separable organization of the brain to 'return' to its 'initial' state. A behavior testing study currently being carried out at this laboratory on cats with bilateral interruption of the mammillothalamic tract will illustrate the complexity of the task. Figure 15 shows the position of the mammillothalamic tracts deep within the brain of a cat. The tract has been interrupted on the left side of the brain by irradiating with focussed ultrasound with a dosage to produce selective destruction of white matter. Positioning accuracy and the geometric scale can be appreciated from the observation that the tract is approximately 1 mm. in diameter. Figure 16 shows a magnified picture of an interrupted tract and surrounding tissue. The animals are trained by an avoidance response procedure. (The animal is placed in a box divided into two halves by a sliding door. The bottom of the box consists of a grid of wires which can be used to shock the animal. If the animal does not cross from one-half of the box to the other in a period of 10 seconds after the door is opened and a buzzer and light are activated he is given a shock.) If the animals are trained to a criterion of response (95 percent success) before interruption of the

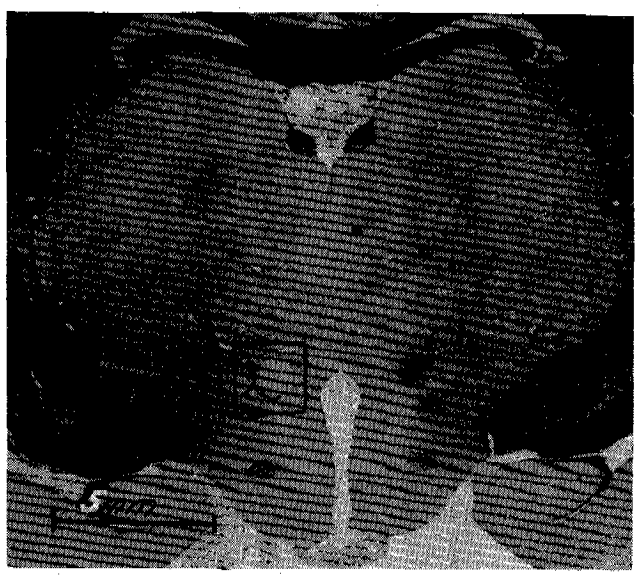

Figure 16 -- A photographic enlargement of the region of the brain containing the mammillothalamic tract. The interrupted tract is enclosed in the box to the left of the middle of the illustration.

mammillothalamic tracts on both sides of the brain, then interruption of these tracts knocks out essentially completely the avoidance response previously trained into the animal. Such animals can, however, relearn the avoidance response and if they are followed by daily testing after retraining to determine the time required, in the absence of the electric shock, for extinction of the response, one finds that a period of time of the order of three to four weeks is necessary. This type of study shows directly that a non-separable type of brain organization is operative -- that is, the behavior of the animal is not invariant with respect to the test configuration (opening of door, turning 'on' of light, sound of buzzer). The study of non-separable organizations of the central nervous system would, therefore, in many instances be expected to cover periods of time of the order of months on a single experimental animal. If many irradiations of the experimental animals are to be distributed in time over such an interval it would not be practical to subject the animals to an operative procedure for each irradiation. And, in fact, if an operative procedure could be avoided it would be possible to work with animals in the 'awake' state. In order to accomplish this it is necessary to develop a sound transparent window which can be inserted in place of the portion of the skull bone which is removed. The development of such a window would make it possible to irradiate experimental animals directly through the skin. The attack on non-separable brain organizations would then be similar to that outlined for the study of separable organizations with the difference that the time scale of the investigations on the same animal would probably be very much longer.

As a result of about a decade of work at the University of Illinois on the effects of precisely controlled high level ultrasound on the tissue of the central nervous system of experimental animals and on the development of appropriate instrumentation for pursuing such work, it became apparent that the method evolved would have application to the study and modification of neurological disorders in humans. Such work has been in progress for the past year and a half as a collaborative program between Dr. Russell Meyers and associates of the Division of Neurosurgery of the State University of Iowa and us of the Biophysical Research Laboratory of the University of Illinois. The first human patients to whom the ultrasonic methods were applied were those in whom changes in the signs and symptoms of the disorders could be identified within a maximum time span of a few minutes to an hour after exposure at an array of sites in the brain. The changes are induced by disrupting the operation of neural organizations involved in the mechanism of the production of the signs and/or symptoms of the disorders. Disorders involving abnormal involuntary movements are being studied, these include alternating tremor (in parkonsinism) and non-patterned movements (in athetosis and dystonia). The muscular rigidity which is present in some parkinsonian patients is also under investigation. Other neurological disorders under investigation at present are those included under the term 'intractable pain'. Individuals experiencing pain of various descriptions and hypersensitivity to touch and other stimuli applied to the skin following amputation of a limb or following cerebral apoplexy have been irradiated in various deep brain structures.

The ultrasonic dosages, at sound levels of 1,000 watts/cm.^{2} and durations of exposure of one to three seconds, employed to induce the changes in the brains of the patients irradiated so far produce irreversible damage to nerve components which is manifested in terms of immediately observable changes in signs and/or symptoms as well as in changes which appear days or months after irradiation. This means that information must be gathered over an extended period of time in order to determine the complete course of response to a given pattern of irreversible lesions placed in specific structures in the brain. However, as indicated above, the disorders under investigation also exhibit changes in times short enough so that considerable information can be gathered on the underlying neural mechanisms during a single irradiation procedure which takes place over a period of the order of one to two hours. These 'immediate' changes are determined by examination and interview of the patient while the multiplicity of individual lesions is placed in the brain structures. Much of our work on humans has involved producing lesions which could not be approximated in shape by any procedure employing mechanical penetration without imposing extreme damage on tissue which must be spared. We have, for example, been employing sheet type lesions, discussed previously in this talk, to separate various brain structures from one another. In such a lesion the extent or volume of the tissue which is irreversibly affected is in the form of a thin curved sheet which corresponds, in many instances, to the boundary between two brain structures. Figure 17 shows a coronal section of one hemisphere of a human brain stained to exhibit the white and gray matter by contrasting depth of stain. (The white matter appears white and the gray matter dark.) This section, taken from a standard stereotactic atlas, shows portions of some of the structures which are of importance in treating patients with abnormal movements. In our researches, ultrasonic sheet lesions have been placed between the red nucleus (labelled R) and the substantia nigra (labelled Ni) for the modification of tremor movements.

As we extend our studies to include disorders which require longer times to manifest changes and which also require more complex tests to detect them than those presently employed for examining and studying the

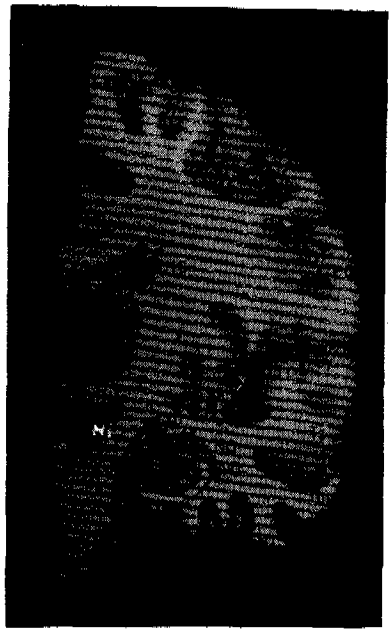

Figure 17 -- A coronal section through one hemisphere of the human brain. (Reproduced from E. A. Spiegel and H. T. Wycis, Stereoencephalotomy, Grune and Stratton, New York, 1952.)

patients during irradiation, we require a technique to make it possible to perform multiple irradiation procedures over long time periods without repetitive surgery. (Only four small incisions for fixing the patient's skull in a stereotaxic apparatus would then be necessary at the time of irradiation.) This new technique consists in irradiating the desired brain structures through the intact skin of the patient after a window has been made in the bone. Structures (not all) on both sides of the brain can be irradiated through a single window. Previous to the time of irradiation, internal brain landmarks are located so that the focus of the sound beam(s) can be positioned at the appropriate sites in the brain structures of interest. On the same day that the coordinates of brain landmarks are determined a bone flap is removed from the patient's skull and a thin plastic sheet may be inserted between the brain covering, or dura, and his skin and muscle. This plastic sheet prevents adhesions and the bone flap can then be left out for a period of time sufficiently long to follow slow changes in the patient and subject him to any number of desired irradiation procedures. (The patient is provided with a helmet to wear whenever there is any danger of injury to the portion of the head from which the bone flap has been removed.) We have already initiated such work and have started the irradiation of patients through the skin. The procedure of irradiating through the skin enjoys a considerable advantage over the procedure of irradiating through the opening in the skin immediately following the removal of the bone flap when the patient has already been subjected to the stress of such surgery. When irradiation through the skin is carried out, the patient is in a very refreshed state, the total time for the procedure being determined almost completely by that required for the irradiation sequence. The remainder of the time is simply that required to place the patient's head in the stereotaxic apparatus and to close the four small incisions in the skin after removal from the head holder. The head of the patient, that is his skull, is held extremely rigidly by the apparatus without discomfort and he is thus capable of engaging in any complex task consistent with his head being held in one position in space. Figure 18 shows a patient with her head positioned in the holder and reclining on her side, which has been the usual arrangement when the sound beam is passed through a lateral opening in the skull. The figure shows the stainless steel rods which rigidly support the skull. The tips of these rods pass through small insertions made in the skin and engage superficial hemispherical indentations in the skull bone. Figure 19 shows another patient with his head in the holder. This view includes one of the X-ray tubes which is utilized in taking pictures of internal brain landmarks. The film holder and tungsten crosshair used in determining the coordinates of the brain landmarks are also shown. The relative configuration of the patient's head, supporting steel bars, ultrasonic transducer and pan for supporting the transmitting liquid is shown in Figure 20. A photograph of the arrangement in the operating room, with skin flap open, is illustrated in Figure 21.

The procedure of irradiating through the skin should make it possible to study very subtle changes induced in the brains of humans by ultrasonic radiation. It will be extremely useful when the 'reversible' procedures are applied in the human program. I might mention here that we have initiated preliminary work on the development

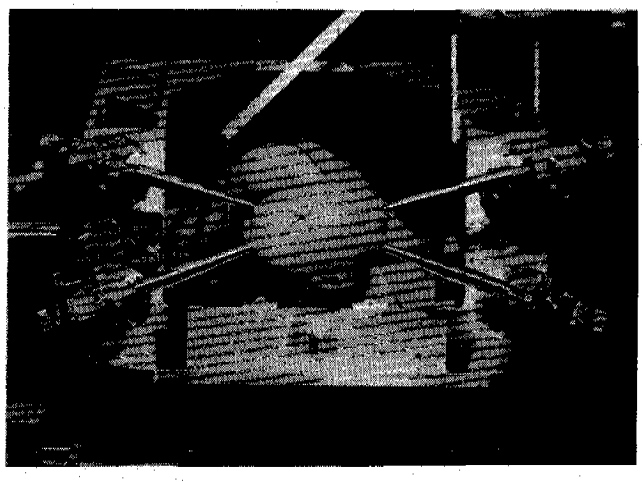

Figure 18 -- A conscious patient with head supported in the head holder. The four stainless steel rods which engage the skull in small hemispherical indentations are shown supported by posts which provide for placement of the tips of the rods at the desired spatial positions. A pointer which is used in the determination of positions of landmarks is shown in front of the face of the patient.

Figure 19 -- A conscious patient reclining on 'operating' table and with head supported in holder. This illustration shows one of the X-ray tubes (right side of figure) and the holder which supports the X-ray film on the left straddling two of the stainless steel supporting rods. The positioning system shown in the upper center of the figure supports a rod which holds the tungsten cross-hairs whose image appears on the roentgenogram to aid in the determination of spatial positions of brain landmarks.

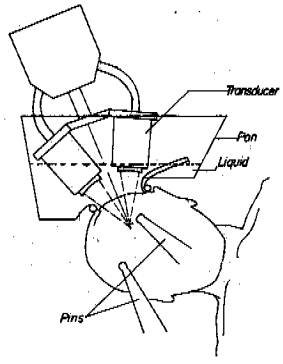

Figure 20 -- Schematic diagram of the relative configuration of the patient's head, supporting stainless bars (pins), ultrasonic transducer and pan for supporting the sterile degassed transmitting liquid.

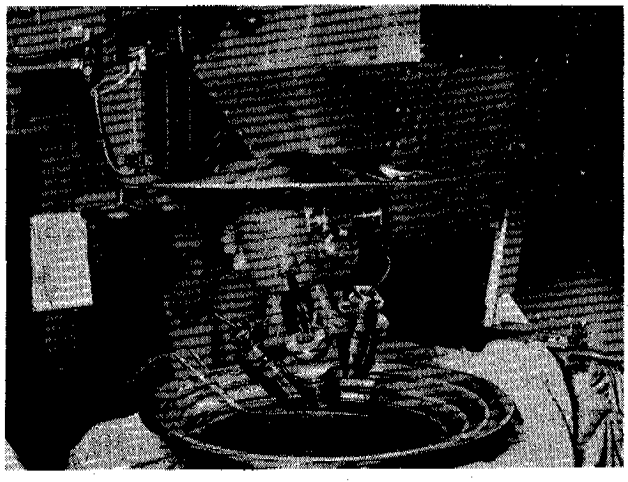

Figure 21 -- Photograph of the arrangement in the operating room showing the pan which supports the transmitting liquid and the four beam irradiator ready for partial submergence into the liquid. The metal coils within the pan are provided to maintain the transmitting liquid at body temperature. The irradiator is moved about in the transmitting liquid to place the focus at the desired sites in the brain.

of an appropriate rigid sound transparent window to replace the bone flap if it is not desirable, in some patients, to leave the individual for a period of time without a rigid plate between the brain and the skin. Such sound transparent windows are technically possible but they will require some time for development and test.

After undergoing a series of examinations, interviews and tests, and irradiations over a period of the order of six months, with the long term changes essentially at an end, the bone flap which was removed can then be replaced by a relatively simple surgical procedure.

A variety of different brain structures has been irradiated in patients suffering from abnormal involuntary movements and muscular rigidity and the irradiation of these different brain structures is being correlated with the results obtained -- that is, the alleviation of tremor, non-patterned movements, and rigidity. The abnormal movements and the muscular rigidity have been very favorably alleviated in most patients on the operating table (33 of 35 patients). Return of symptoms has appeared in some patients but never to the original degree. (The new procedure of irradiating through the skin will permit continuing the ultrasonic treatment of patients with some return of symptoms.) In intractable pain patients, it has been possible, by appropriate irradiation, to completely eliminate all discomforting sensations and hypersensitivity to touch or other stimuli without producing any observed sensory deficit. Although we have not yet succeeded in determining, for the intractable pain cases, a suitable irradiation procedure which completely eliminates these discomforting sensations essentially permanently we have already obtained much valuable information on fundamental brain mechanisms which will ultimately result in the development of new therapeutic procedures.

It is expected that when an ultrasonic therapeutic procedure is developed for the treatment of a specific neurological disorder its employment will result in a minimum mortality and patient morbidity. This is concluded because the blood vessels in the sites in which the neural components of the brain tissue are destroyed are not interrupted and because the brain is not manipulated or penetrated by mechanical instruments. This view is also supported by the results of the extensive research accomplished on experimental animals.

I feel that ultrasonic methods are potentially useful for investigating the mechanisms of practically all types of behavior in both experimental animals and in humans. The use of ultrasonic dosages which produce only reversible changes will be particularly useful in studies of basic mechanisms of operation of the central nervous system.

It is hoped that the usage of the terms 'organic' and 'non-organic' brain disease will soon disappear. Statements to the effect that certain activity or behavior in humans is psychological in nature, with the implication that it cannot be modified by inducing changes in brain mechanisms and/or that a wide variety of tools are thereby excluded from use are devoid of any scientific basis. It is my personal opinion that these terms (organic and non-organic) have outgrown any usefulness they might have had in the past and that their continuing employment will simply hinder further progress.

Direct observation would suggest that much present human activity should be either modified or eliminated. This might appear to indicate that some design changes in the mechanisms of operation of the central nervous system would be desirable for the human population in the large. To assume that the present mechanisms of operation of the human brain are 'optimum' for a device to produce or engage in intellectual and creative activity is nothing but a propagation of the old heliocentric doctrine applied to the brain. One cannot, of course, prove that modifications of present human brains would result in a more 'desirable' type of behavior without much more knowledge of the details of present brain mechanisms. It may turn out of course that it would be more fruitful to start from scratch but ultrasonic methods should, in conjunction with other procedures, permit us to come closer to answering such questions.

THE RADIATION ENVIRONMENT OF THE EARTH

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It is my pleasure to speak with you on some of the contemporary advances in a field of study we now call the science of space.

I have for sometime been seeking (with but dubious success) a proper definition of the term, space. Several of my colleagues have recently urged me to devise a definition. My best effort up to the present time is herewith offered: 'Space is that in which everything else is.' Consistent with such a definition, the science of space would be a rather hollow subject. What we are in fact concerned with is the science of what is in space. This is certainly a broad enough subject to engage the interest of scientists for some time to come. The chief topic of my talk concerns a small subdivision of space science, namely, the contents of space in the immediate astronomical vicinity of the Earth.

It is reasonable to suppose that humans have been peering out into space for as long as the race has existed. A small sample of this population, the astronomers, have brought a great deal of perceptual sagacity to the business of peering. With increased vigilance and the technical advances of recent years, astronomers have collected a vast amount of data on a daily and, in some instances, an hourly basis. During the International Geophysical year the sun has been under continuous observation from a suitable distribution of stations around the globe.

Among other striking phenomena observed by the astronomers have been the great flares of visible, cloud-like materials that shoot outwards from the sun's surface, fading away into the distance and/or dropping back to the region whence they issued. For some fifty to one hundred years it has been known that these solar eruptions are often, though not invariably, followed approximately a day later by a great display of lights, called 'aurorae,' seen most conspicuously from the relatively northerly regions of the Northern, and the relatively southerly regions of the Southern Hemispheres.

Despite the lack of direct evidence providing incontrovertible proof, the frequent temporal sequence between solar flares, on the one hand, and aurorae in the atmosphere of the Earth, on the other, has persuaded many astronomers that the two events are causally connected.

The intermediate events involved in these striking phenomena entirely escaped detection until February, 1958. It now appears that such occur in the relatively close surround of the Earth, namely, in its radiation environment.

Some persons identify the beginning of the Age of Space as 4 October 1957, the date on which the Russian satellite, Sputnik I, was launched. With this I am not wholly in agreement, for the science of astronomy has long been dealing with outer space and for a number of years we have been shooting rockets into outer space. Such endeavors have yielded much valuable information upon which our current procedures are in considerable measure based.

I wish now to list in chronological order the space vehicle flights made since 4 October 1957. These have furnished the empirical data from which certain of the interpretations I plan to disclose have been derived.

Sputnik II	(U.S.S.R.)
Explorer I	(U.S.A.)
Explorer III	(U.S.A.)
Sputnik III	(U.S.S.R.)
Explorer IV	(U.S.A.)
Pioneer I	(U.S.A.)
Pioneer II	(U.S.A.)
Pioneer III	(U.S.A.)
Mechta	(U.S.S.R.)
Pioneer IV	(U.S.A.)

The first satellite measurements of the radiation environment of the Earth were made by Sputnik II which was fired in November 1957. The second measurements were made by Explorer I, which carried apparatus designed and executed in the Physics Laboratory of the State University of Iowa.

In retrospect, these firings represent a more or less interlaced series of events which occurred during an important period of nip-and-tuck developments by the Russians and ourselves. All this has permitted an unprecedented dovetailing of data which, in its turn, has made possible an interpretation of results that

could scarcely have been reached in any other way than by the impetus and pattern-of-working provided by the I.G.Y. While the Soviet Union and the U.S.A. may not agree in regard to the disposition of Berlin, it is certain that we can reach ready agreement in the realm of physics.

It is now about 13 years since my colleagues and I at Iowa began to study the intensity and distribution of cosmic radiation above the Earth's atmosphere. Our space probes consisted mainly of rockets having a relatively small range. In 1947, I communicated a paper to an international conference in Oslo, synopsizing my findings as obtained up to that time by such means. In the course of this paper, I suggested that it might be of enormous advantage if someday we could launch a satellite that would orbit around and around the Earth, thus permitting us to sit at home while we comfortably received the data picked up by our satellite. In this way, I thought, we might spare ourselves the fatigue and inconveniences involved in carrying apparatus to and making observations at various (sometimes quite remote) places in the world.

The prospect of implementing this idea did not become realistic until eight years had passed. Then, in July 1955, the President of the United States announced that the launching of satellites for scientific purposes had at last been judged feasible and that, as part of our national contribution to the I.G.Y., this would be attempted under the aegis of the National Committee.

Meanwhile, a number of us had been planning what we would do if we were ever given the opportunity to place observing equipment aboard a satellite. We were, in fact, quite well prepared for it.

Our first opportunity came in 1958 when Explorer I was fired on 31 January. This satellite carried our apparatus, the entire design of which incorporated the knowledge and understanding reached up to that time by our previous studies of cosmic rays. While such information as we then possessed had been gained by intensive studies during a period of over ten years, it was, geographically speaking, all too fragmentary.

In a very real sense, our experiences with Explorer I exemplified serendipity-in-action, what might be freely translated as 'fool's luck.' We had started out to investigate cosmic radiation in a scientifically respectable but none the less pedestrian undertaking. Then, within a few days of the launching of Explorer I we began to get reports that suggested that our endeavor either constituted a sizable failure or we had uncovered a wholly unexpected, almost unbelievable, finding.

It was hard for me to accept the former possibility for the reason that I had never before had a more basic confidence in the proper functioning of any apparatus than that reposed in the instrument we had so painstakingly developed and so critically checked before sending it aloft.

Meanwhile, we had prepared a second apparatus which was carried by Explorer II (launched on 5 March 1958). Although this vehicle fell into the South Atlantic some ten minutes after the launching, our apparatus performed well and tended to support our confidence in the data brought to us by Explorer I.

Explorer III was launched on 26 March 1958. This constituted a successful flight. It contained a similar but not identical apparatus to that carried by Explorers I and II. It was, in fact, more 'sophisticated' or 'intelligent,' in that it was more complex and discriminating than either of the previous instruments.

The very first record obtained with this apparatus revealed, at altitudes of about 1000 kilometers above the Earth, a totally unanticipated physical effect, a phenomenon of nature existing on a vast scale and having a great significance for connecting events on the sun with those of the Earth. This physical effect is illustrated in the artist's conception (figure 1) in which the solid, physical Earth appears as a ball in the center. Encircling the Earth in the equatorial

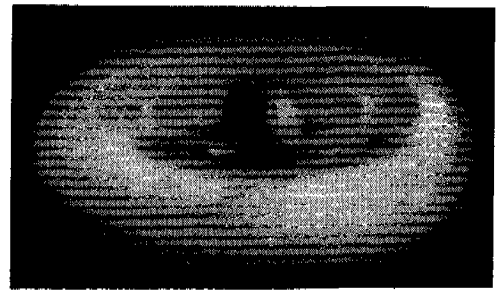

Figure 1

plane is a relatively thin 'inner radiation zone,' somewhat in the form of a wedding ring; and beyond this is a much more diffuse and extensive 'outer radiation zone.' These 'rings' consist of electrically charged particles confined or 'trapped' in the magnetic field of the Earth.

One should not interpret figure 1 as representing what an observer might photograph from some observatory outside the Earth, such as the moon. It is, rather, an artist's concept of what one might 'see' if he had Geiger counters instead of ordinary eyes, and if he flew around and around the Earth in a satellite orbit.

Figure 2 illustrates our piece of apparatus as carried by Explorer I. The cylindrical shell on the

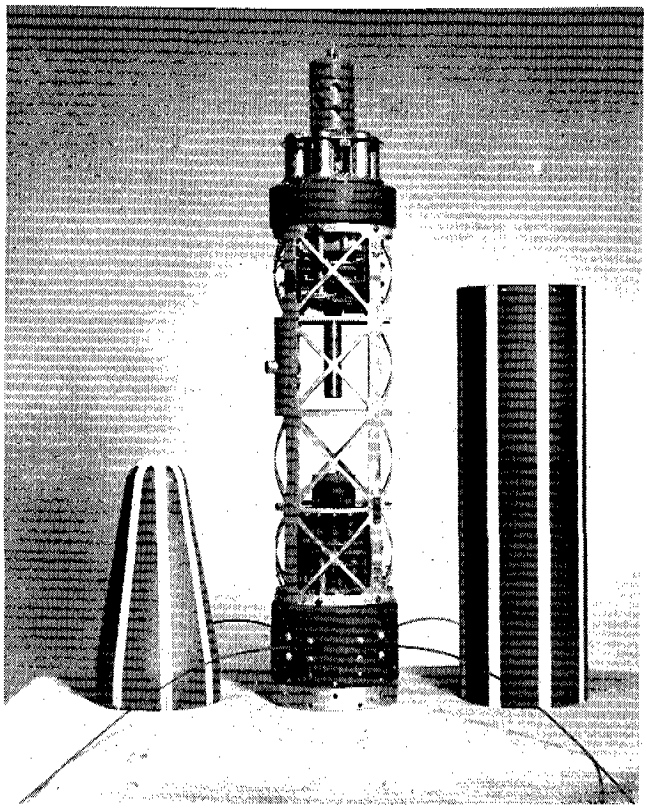

Figure 2

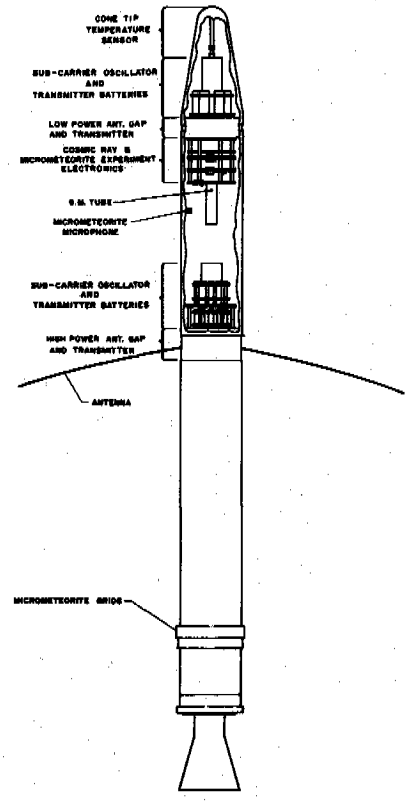

Figure 3

right has a diameter of about six inches. The element at the center of the figure represents the 'heart' of the instrument -- a small Geiger-Muller tube. This is connected to a miscellany of electronic apparatus which enables a signal to go out over the radio-carrier and thus to be communicated to appropriately situated receiving stations on the ground.

Figure 3 illustrates the over-all configuration of the slender tube which comprised the orbiting body of Explorer I. The four wires seen projecting from the side of the rocket serve as radio antennae.

The experimental results derived from Explorer I are typified by figure 4, in which the altitude has been plotted horizontally against the counting rate ('intensity' of radiation) of the Geiger tube. The graph represents the findings obtained on a so-called quiet or ordinary day. In order to represent a conveniently large range of radiation intensities on a single graph, a logarithmic scale has been employed. One sees, then, ranges representing 10's, 100's, 1,000's, and 10,000 units of radiation, each increment representing an increase by a factor of 10 over the just previous range. The graph indicates that at a typical altitude of about 800 kilometers (approximately 500 miles) the intensity of radiation increases very rapidly.

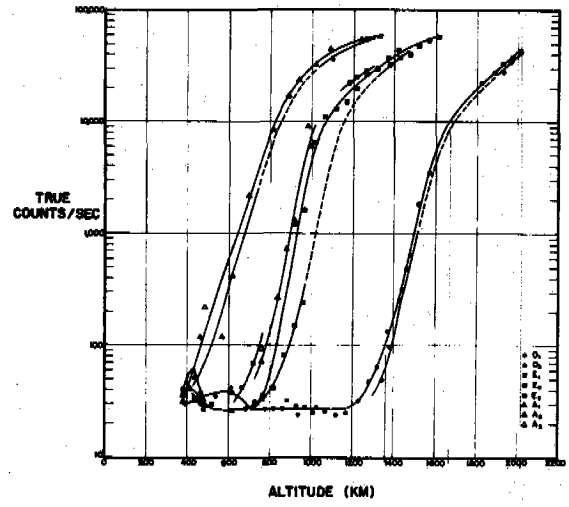

Figure 4

In considering these findings we should recognize the fact that the effective 'thickness' of atmosphere around the Earth between, say, 600 kilometers and 1000 kilometers is very minute in comparison with the wall thickness of the apparatus. The ratio is, in fact, less than 1/1,000,000. This fact poses the

question as to how radiation which can pass through the wall of our counter apparatus should be so strikingly influenced by a little bit of additional atmosphere. At first encounter this seems inconceivable and most certainly so for X-radiation, neutrons and any other neutral, uncharged particles. The dilmema is at once resolvable when we recall that, in addition to the atmosphere encompassing the Earth, the latter possesses a magnetic field. Charged particles can, by this circumstance, be deflected and thus prevented from coming down to the Earth. In this way the magnetic field acts as a sort of net which traps charged radiation and holds it away from the Earth.

Within an hour of the receipt of the first records from Explorer III we concluded that, whatever we were measuring, it must consist of charged particles and that the magnetic field of the Earth is an essential feature in determining and controlling the radiation belt(s) around the Earth.

Some idea of the make-up of Explorer III may be obtained from Figures 5 and 6. The lower portion of the apparatus as shown in figure 5, from all outward appearances, might as well be a can of soup. In

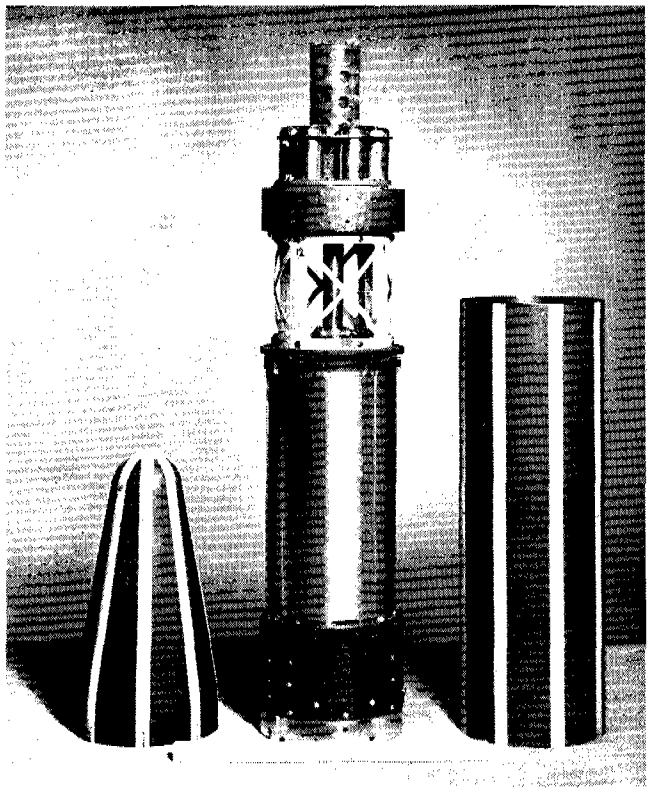

Figure 5

actuality the can constitutes the 'instrumentation package' and contains a Geiger tube; a miniature magnetic-tape recording device; a radio receiver ('command receiver') which receives signals from the ground and performs certain other functions; and a playback transmitter. These are more clearly explicated in figure 6. There are, in addition, a number of other miscellaneous electronic components which need not engage our attention at this point. The lowermost portion of the package contains racks of batteries ('battery modules') for powering the apparatus.

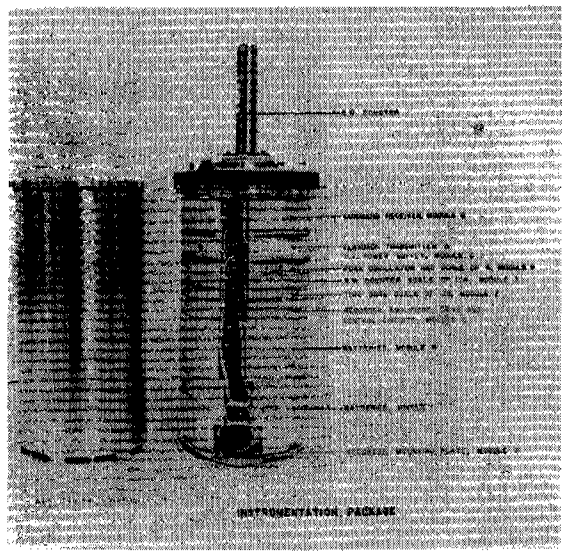

Figure 6

Each deck contains several hundred electronic components, arranged to perform certain functions. Some decks represent a year's work for one man in designing and building them.

One of the urgent demands on such apparatus calls for its ability to withstand thermal and electrical protection under the stringent conditions involved in the firing of the rocket. Such protection is provided by 'potting' the decks and other delicate parts in soft plastic foam.

One of the most important devices in the 'can' is a miniature magnetic tape recorder, designed under my general guidance by one of our capable graduate students, Mr. George Ludwig, to record all data derived during one complete trip of approximately two hours around the Earth (figure 7). This information is stored on the tape and then, upon radio command, is released within six seconds as the satellite makes an optimal approach to one of the ground receiving stations.

The electrical power employed for all this is expressed conveniently in milliwatts and thus is extremely small -- about one millionth of that used by large commercial radio broadcasting stations (which measure their power in kilowatts).

The previously used arrangements were capable of recording and reporting only fragments of the total data available. In contrast, the device just described

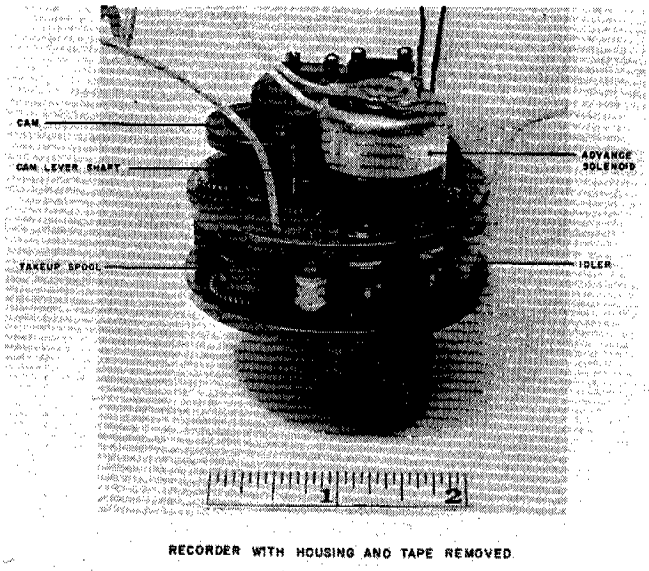

Figure 7

is capable of recording continuously even when the satellite is, from a radio point of view, 'invisible' from the ground stations. We therefore regard this miniature tape recorder and transmitter as a considerable technical achievement. On board Explorer III it proved to be the hero of my story, confirming what we could only surmise was going on in outer space from the flight of Explorer I.

When the time came to prepare Explorer IV for flight, our background knowledge had made us more generally familiar than we had ever been with our objects of inquiry, especially with the magnitude of intensities of radiation with which we had to deal and with what was needed, instrument-wise, to learn more details about the nature of the radiation and its intensity and distribution in space. Working under considerable pressure because of the time schedule adopted for launching Explorer IV, we undertook to design and build a yet more discriminating apparatus. This went into orbit on 26 July 1958. Among other features, it carried two transmitters, two detectors using scintillating crystals and two Geiger-Muller tubes. A network of some 30 receiving stations distributed over the globe was set up and operated on a voluntary basis. Each station was equipped with a magnetic tape recorder. The big roll accumulated during each day at each station was mailed to us for detailed study at Iowa City. The process of collecting data in this way continued from 26 July to late September 1958, at which time the batteries on the satellite became exhausted. We now have in one corner of the basement of the Physics Building at Iowa City the world's largest working collection of satellite observations -- larger by a factor of 10 (perhaps of 100) than that of any other in existence. Each one of the tapes requires for analysis and interpretation approximately one week of work by an intelligent person. From Explorer IV alone we have at hand some 3,600 'passes,' each one representing the telemetered record of data collected during a period of from several to 30 minutes. Each such 'pass' is the 'equivalent' of one good old fashioned rocket flight as of two years ago. In point of fact, since the data on many of these tapes cover a much longer period of time than we could ever have hoped to record by means of single rocket flights (many of which would, in addition, have had to be made from remote islands and aboard ship at various points at sea) our tapes represent more nearly the equivalent of 10,000 than a mere 3,600 rocket flights. Obviously, then, a satellite is, as a scientific 'observing machine,' vastly productive.

Many of us have spent day after day reading the data recorded in the manner described and attempting to understand it. I judge that we have by now gleaned the main points furnished by Explorer IV, although we will no doubt be able to spell out some newer details of interest five years hence.

The data make it abundantly clear that space in the vicinity above the Earth is not empty. And I'm sure that what has been revealed so far is but one of a number of types of beautiful phenomena yet to be revealed as space science undergoes further development.

The geographical extent of 'coverage' of the world accomplished by our little package orbiting around the Earth is illustrated in figure 8. This exhibits but a few samples of the 'shadows' cast by the

Figure 8

apparatus upon the Earth's surface. The starting point was in east central Florida and, in its first course, the moving 'shadow' nicked the corner of Newfoundland. After reaching a maximum of northerly excursion, the 'shadow' moved southward across France, etc. Subsequent excursions of the 'shadow' are delineated on the illustration as they 'shifted' due to the rotation of the Earth under the satellite.

Explorer IV made some twelve round trips per day and, although its batteries went dead in late Sep-

tember, it remained in orbit about 15 months and travelled over 150 million miles. Hence, granting that it is an expensive undertaking at the outset to get a satellite into orbit, if one figures miles per gallon it proves to be an extremely inexpensive vehicle.

We have by now surveyed the radiation phenomena occurring in space around the Earth from a lower altitude of about 220 to an upper altitude of about 2,200 kilometers and ranging between latitudes corresponding to the southern tip of Hudson's Bay in the Northern Hemisphere to Cape Horn in the Southern Hemisphere.

We come now to the description of a series of 'deep-space probes,' exemplified by Pioneer III (figure 9).

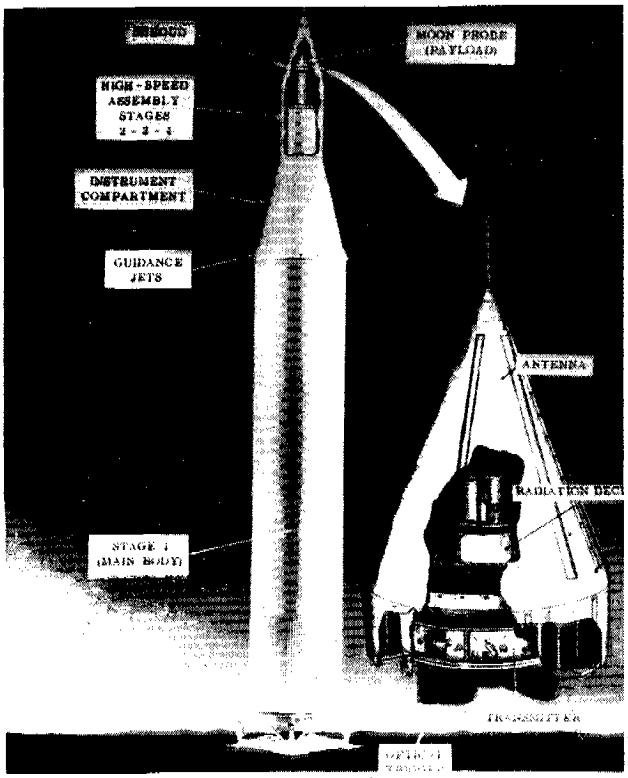

Figure 9

The overall engineering of the 13 pound payload of this vehicle was implemented by the Jet Propulsion Laboratory of Pasadena. Again, the heart of the apparatus was developed in our Physics Laboratory. This element, weighing about two and one-half pounds, was designed to measure the radiation at very great distances from the Earth -- much exceeding that of satellites (which, on an astronomical scale, actually spin around in the immediate vicinity of the Earth). Pioneer III, on the other hand, was designed to make a survey of the radiation intensities prevailing at considerably greater distances from the Earth. It was originally called a 'lunar probe' and, somewhat later (after it had missed the moon by some 200,000 miles) a 'space probe.'

To throw such a 'payload' package weighing 13 pounds (and with but 2 1/2 pounds of which I am intimately concerned) toward the moon requires a monster machine weighing 70 tons. This proportion graphically illustrates the technical difficulties that confront those seriously interested in the problems of space flight and travel.

The orbit of Pioneer III, the deep space probe which was launched on 6 December and which returned on 7 December 1958, is represented in figure 10.

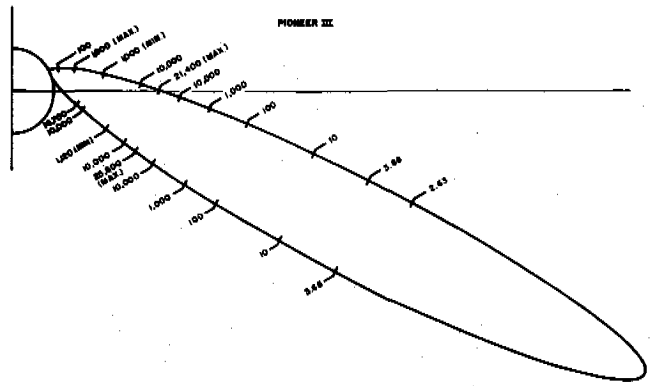

Figure 10

On the left of the diagram is seen a cross-section of the Earth. The 'outgoing' and 'returning legs' of the flight are apparent. The round trip consumed, in all, some 37 hours. Although the probe did not go as intended into orbit around the moon, it was, from our point of view, a very fine flight.

The numbers on the two 'legs' indicate the observations of radiation intensity at corresponding distances from the Earth.

The data thus collected were now re-plotted, using the geomagnetic axis of the Earth as the 'axis of symmetry' (figure 11). A cross-section of the Earth

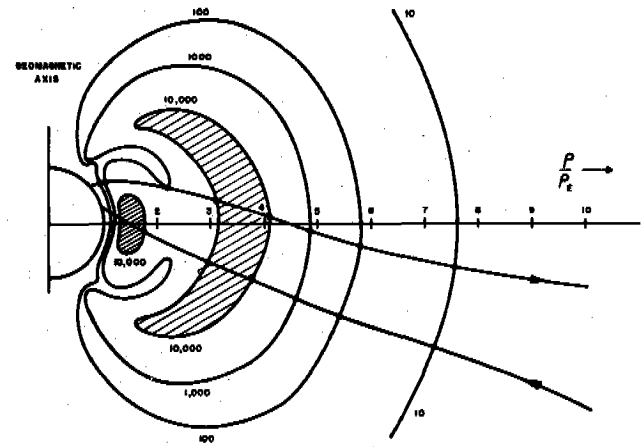

Figure 11

is again represented on the left. The heavy gently curved lines represent the traces of Pioneer III going outwards from and returning to the Earth. The lune shaped curves show the inferred contours of certain radiation intensities around the Earth. Thus, at the cites marked 10, 100, 1,000 and 10,000 the intensities empirically encountered are expressed as corresponding 'units.' (These findings were later well confirmed in regard to space near the earth by Explorer IV.)

In brief, there appears to exist an inner region, fairly close to the Earth, in which the radiation intensity exceeds 10,000 units. In cross section, this exhibits the general shape of a lima bean. Then, going through sequences of minima and maxima as we move away from (or approach) the Earth, we encounter an outer region which, in meridian cross-section, exhibits the general shape of a banana. Each of these two figures -- the lima bean and the banana -- must be understood to generate figures by revolution around the axis and thus to provide what resemble rings or belts around the Earth.

I must now hasten to add that a good part of this diagram is speculative. Our best established experimental data bear reference to the regions about one-third of the radius out from the Earth. The portions of the diagram more remote from the Earth than this represent freehand sketching based upon the somewhat more meager experimental observations currently at hand and harmonized with what is known regarding such factors as the 'shaping' influence exerted upon charged particles by the Earth's magnetic field. Nevertheless, I represent this diagram as being in essence the radiation situation surrounding the Earth in real scale and in quantitative measure, for I think that, given the data at hand, no one could prepare a simple diagram which would differ substantially from that here offered.

We are not, of course, at liberty to assert that the present diagram is time-stationary. It represents the situation that obtained on 6 December 1958. However, as revealed by Explorer IV, only temporary perturbations in the configurations here represented have occurred during the ensuing two months; and no radical changes appear to have taken place from July to December 1958.

In further explication regarding 'magnetic trapping' around the Earth, we may envision a magnetic line of force extending from a northerly point in Europe to a southerly point in the Indian Ocean. The motion or trajectory of a charged particle along that line of force exhibits a helical pathway. This is the type of motion we believe in general to be taking place in the trapped radiation around the Earth. Moreover, while the spiral is generally loose or stretched out near the equator, it becomes progressively tighter as one recedes from the equator. Where the spiral is most tight and flat (a region called the 'mirror point'), the motion of the charged particle is reversed. The typical particle speeds thus from a point over Europe to one over the Indian Ocean in less than a second, then retraces its path to the Northern Hemisphere, etc.

In addition to this oscillatory motion from the Northern to the Southern Hemispheres, negatively charged particles (e.g., electrons) apparently exhibit a continuous 'drift' of motion toward the East. Contrarily, positive particles exhibit a 'drift' to the West. The drifting motion of charged particles constitutes an electrical current encircling the earth.

Pioneer IV, in which we again had a piece of apparatus similar to that used before but carrying one relatively unshielded Geiger tube and (for the first time) a second tube fairly heavily shielded by lead, was sent aloft on 3 March 1959 -- six weeks ago. The data on radiation intensity derived from this probe extended far beyond that derived from Pioneer III. At a distance of about 15 times the radius of the Earth, the counting rate settled down to a steady value of about one impulse per second. This rate then continued until the apparatus had flown well beyond the moon. Continual radio observation was maintained until the probe reached a range of about 640,000 kilometers (about 100 times the radius of the Earth). Thus far, this is the greatest distance from which man-made radio signals have ever been received.

The results obtained from scintillation counting devices aboard the Soviet 'moon flight,' Mechta, on 12 January, were summarized in Pravda of 6 March 1959 by two well known Russian satellite workers, Vernov and Chudakov. Their diagram exhibits data from as far above the surface of the Earth as 150,000 kilometers. Their findings are fully consistent with and corroborative of ours. Such minor deviations as are discernible may be interpreted as being due to the use of a more northerly site of the Soviet launching pad than that of ours in Florida. This resulted in the outgoing leg of Metcha's flight passing through only the 'corner' of the inner radiation zone.

Insofar as the nations of the world are concerned, the scientific investigations subsumed by the I.G.Y. may be looked upon as a peaceful competitive enterprise -- a kind of scheduled international Olympic games, using satellites, rockets and space probes (and various scoring criteria). The investigations have been supplemental to one another, in the sense of exchanging information, rather than cooperative, for the most part. But this represents an enormous advance and, of course, carries a high potential for relieving international tensions. We should remind ourselves that two years ago results obtained would not have been shared. The data so collected would have been jealously 'classified' by

the governing bodies of each side. Indeed, we might postulate that, but for the I. G. Y., the data might not have been sought at all, at least in the present era. At any rate, as a result of the I. G. Y., we are all in substantial agreement on the general nature of the radiation environment of the Earth.

It must be impressed upon the interested citizen that the data thus far obtained by the Russians and ourselves relate to a period of maximal solar outbursts. The data of four or even of three years hence may (and probably will) prove to be quite different. The findings of any period may be expected to change.

Finally, we may speculate briefly upon what current results imply with respect to radiation trapped around other planets. (In space travel, such a matter is bound to become a very pragmatic matter.) So far as we can now judge, it appears very likely that any celestial body which has a magnetic field resembling the Earth's and which does not have 'too much' atmosphere (i.e., atmosphere extending outwards to such an altitude as to severely absorb the radiation) will favor the appearance of a belt or belts of trapped radiation.

THE ANNUAL ALFRED KORZYBSKI MEMORIAL LECTURES

1952, William Vogt, ecologist
'On Structure and Survival.'

Ashley Montagu, anthropologist
'On Time-Binding and the Concept of Culture.'

1953, F. J. Roethlisberger, Harvard University
'Human Relations in Industry: A Problem of Communication.'

1954, F. S. C. Northrop, Yale University
'Mathematical Physics and Korzybski's Semantics.'

1955, R. Buckminster Fuller, designer and engineer
'General Structures Investigations and Korzybski's Formulations.'

1956, Clyde Kluckhohn, Harvard University
'General Semantics and "Primitive" Languages.'

1957, A. H. Maslow, Brandeis University
'Two Kinds of Cognition and Their Integration.'

1958, Russell Meyers, MD, State University of Iowa
'Potentials of General Semantics in the Age of Space.'

The lectures, with the exception of R. Buckminster Fuller's, have been published in the Bulletin.