INSTITUTE FOR BIOMEDICAL ENGINEERING

SOME OF ITS PROJECTS
SOME OF ITS PEOPLE

UNIVERSITY OF UTAH

(UNCORRECTED PREPRINT)

The Division of Artificial Organs

Bldg. 518

The University of Utah Campus at Salt Lake City, Utah

September 1973

I N D E X

I. ARTIFICIAL KIDNEY:

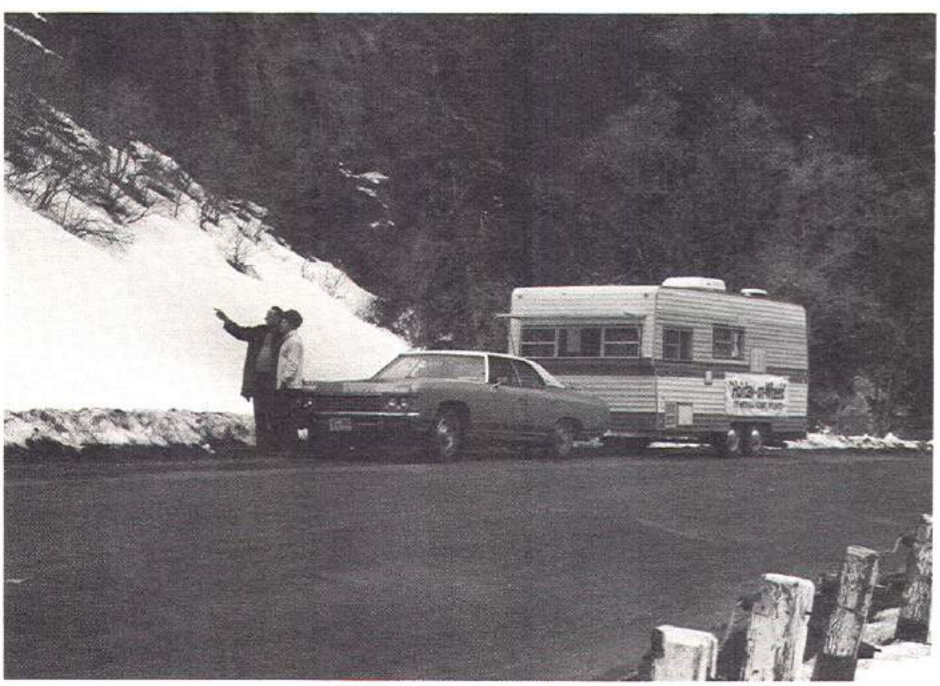
Dr. W. J. Kolff made the first clinically useful artificial kidney. The first patient was treated in 1943. Ever since, the development of artificial kidneys has been further pursued - partly from purely practical points of view. Home Dialysis was promoted; it cost $5,000 per year whereas hospital dialysis cost $25,000 per year. To reduce the cost of the dialysis itself, we tested an artificial kidney with disposable insert costing $5.50 as compared to $15 for disposable coil dialyzers. Midimolecules, thought to play an important role in the clinical picture of uremia, can be removed by charcoal type artificial kidneys. Dr. Andrade has coated charcoal with PolyHema or Hydron so that it loses its damaging effect on blood, yet retains its adsorptive action.

The first patient whose life was probably saved by the artificial kidney. She was treated on Sep. 11, 1945 in Kampen the Netherlands. The picture was taken approx. 4 weeks later.

Single needle dialysis was recently introduced in the United States by us. A wearable type of artificial kidney is under construction. In the coming years, we will perfect wearable artificial kidneys that by adsorption of midi-molecules and by ultrafiltration will mimic more closely the natural kidney function.

Work with the artificial kidneys has led to the elucidation of renal and renoprival hypertension, and this is now carried to clinical application. Intractable hypertension in uremic patients may lead to a necessity to take both kidneys out. The artificial kidney has led to kidney transplantation, and our team treats patients before and when needed after transplantation.

The Division of Artificial Organs administers the Home Dialysis Training Center. More than 50 of our patients treat themselves with artificial kidneys at home in the intermountain area. We even have the possibility of allowing them a vacation with their artificial kidney inside a trailer via the Rotary Club of Murray. We call this Vacation Dialysis on Wheels.



II. GROWING NEW BLOOD VESSELS:

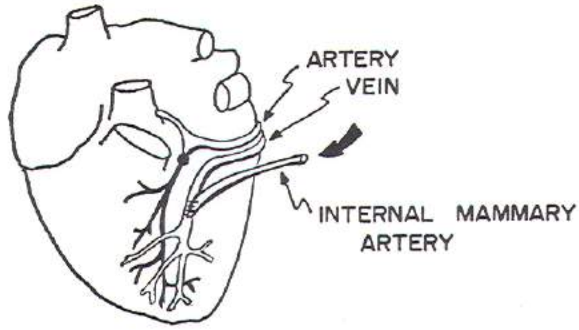
New blood vessels had to be grown to provide puncture sites for dialysis. This led Dr. Jay Volder to the use of porous Gore-Tex grafts which promises to have wide applications in cardiovascular surgery. Connective tissue cells grow into the pores and form a living new blood vessel wall. In the coming years, we will grow not only blood vessels, but also other hollow organs - trachea and heart ventricles.

Gore-Tex Graft

III. HEART-LUNG MACHINES AND REVASCULARIZATION OF THE MYOCARDIUM:

In 1949, Dr. W. J. Kolff began work with heart-lung machines which led to the first membrane oxygenator used in clinical application and also to the first application of elective cardiac arrest in the United States. Presently, an active program pursues the revascularization of the blood deprived areas of the heart muscle.

In the coming years, we will further explore means to vascularize the myocardium.



Internal mammary artery anastomosed to the specific vein that drains a blood deprived area, to restore its blood supply. This method originated in our laboratory and shows promise.

IV. CARDIAC ASSIST DEVICES AND TOTAL HEART REPLACEMENT:

We specialize in closed chest methods to support the failing heart. The intra-aortic balloon pump originated in our laboratory in 1961; others were initiated more recently - transarterial left ventricular bypass (Dr. Zwart) is one. Our aim is to develop and perfect them for clinical use and to determine not only their effect upon the circulation, but also their effect on improvement of the failing heart muscle. So far, decompression of the left ventricle seems most beneficial. In the coming years, we will further develop cardiac assist devices. Transapical left ventricular bypass is one. We will carry them to clinical perfection and are aiming for long-time support. Future patients will progress from cardiac assist devices to the artificial heart.

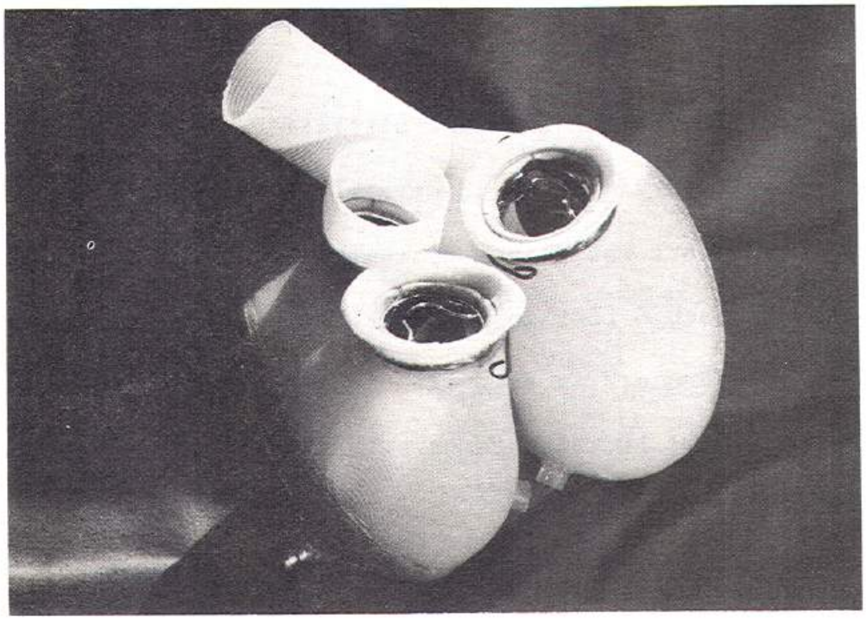
Our artificial hearts are driven by compressed air, have no electronic controls inside the chest - yet respond to Starling's Law. The physiological responses of the circulation are quite good.

In April 1973, in the Division of Artificial Organs of the University of Utah, a calf survived for 18 days after removal of its natural heart. Its artificial heart was driven by compressed air which entered the chest through two tubes, each 6 feet in length. The clinical condition of the calf was good. This calf, "Bruce," is seen with John Lawson's biographical sketch (page 24). There are still limiting factors that need to be overcome. They are listed below:

1. Problems of clotting of the blood on the inside of the artificial heart pump. This is being studied in cooperation with Dr. Ed J. Hershgold. A rough intima inside the artificial heart has reduced this problem.
2. Lung problems thus far not clearly understood. They are comparable with hyalin membrane disease or respiratory distress syndrome seen in premature children (Baby Kennedy). This is being studied by Dr. Don Olsen and Dr. Ted Stanley.
3. A syndrome that resembles right heart failure which is probably due to impedance of the inflow of the animal's blood to the right side of the artificial heart. We believe that we have overcome this to a large extent. It is being pursued by Dr. Hartmut Oster, Dr. Jeff Peters and Mr. Rob Jarvik.

In the coming years we will perfect artificial hearts with power source outside the body to the point where they will be clinically applicable. We expect that reasonable rehabilitation will be possible of human heart patients willing to carry this relatively simple device.

The Jarvik Heart

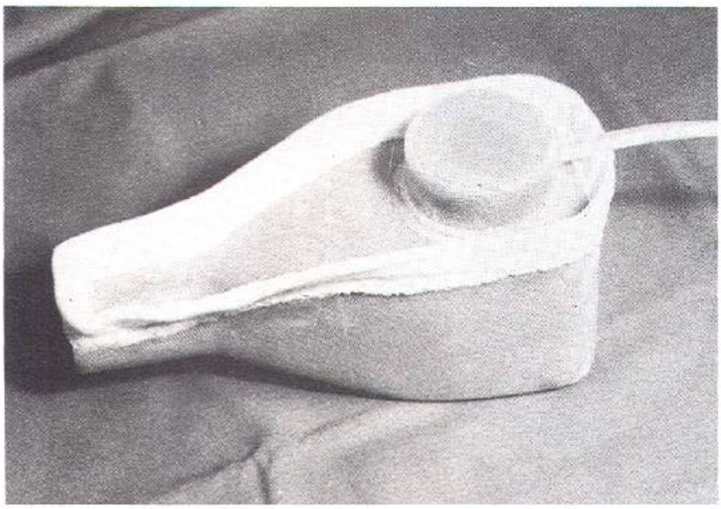


The insertion of an artificial heart into an animal is difficult. It takes the same operating room team that is required for the most extensive heart surgery in man. The postoperative care of an animal with an artificial heart inside the chest is even more difficult than the postoperative care of a patient after heart surgery. We do not have private duty nurses, but we do have specially trained personnel which attend the calf 24 hours a day and try to make the calf as comfortable as possible.

V. THE ATOMICALLY POWERED ARTIFICIAL HEART:

In collaboration with the Atomic Energy Commission and Westinghouse Corp., our Dr. Donovan and Dr. Backman analyzed the power requirements of an artificial heart and then helped in the design of an artificial heart which is driven by a radio-active plutonium source which will be totally implanted inside the body. This artificial heart will be of a soft shell design. The power will be transmitted via a rotating shaft which comes from the abdomen through the diaphragm into the chest cavity.

Application of the atomically driven heart lies further in the future than the hearts with power source outside the body. The specific assignment of the Division of Artificial Organs is to fabricate blood handling parts. Our experience and facilities to work with various elastomers, silicone rubber (Tom Kessler); polyurethanes (Dr. Lyman), the ability to mold and model various artificial hearts and to analyze and implant them are all put to work in this combined program.

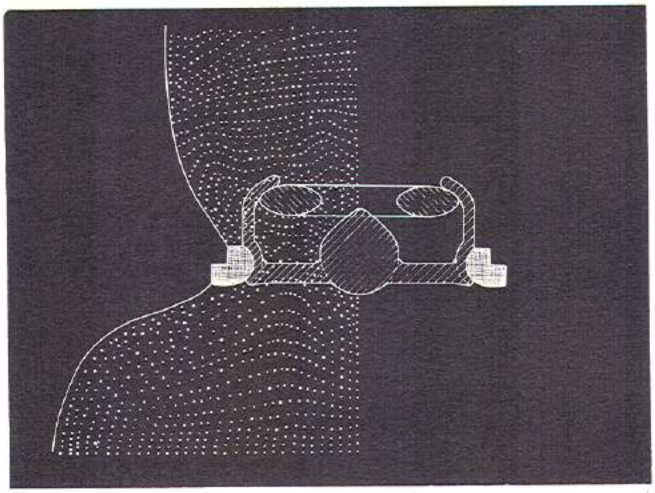


Model of Atomic Engine

VI. COMPUTER GRAPHICS:

Dr. Harvey Greenfield is a member of the Division of Artificial Organs. He has been with us for six years. He uses computer graphics to demonstrate and calculate flows and turbulences of blood and stresses in heart valves and blood vessel walls.

In the coming years, computer graphics in the study of the circulation will be more and more recognized as a method with unique and great possibilities.



Particles following through a Toroidal Valve simulated by a computer.

VII. INSTRUMENTATION TECHNIQUES:

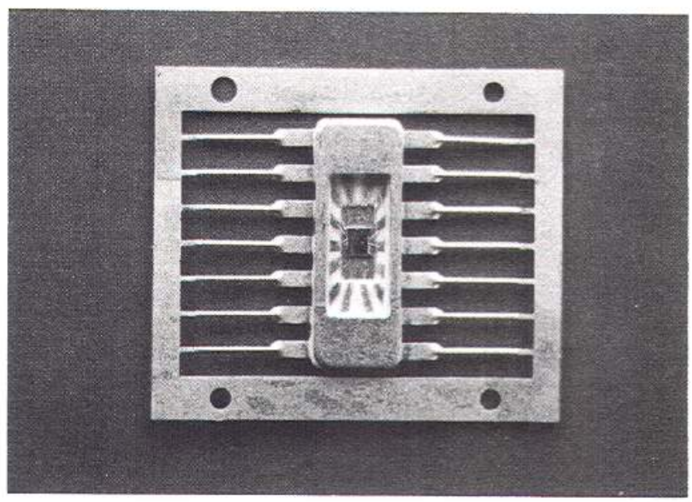
Dr. Curtis Johnson is Dr. Kolff's co-director of the Institute for Biomedical Engineering. He is located in the College of Engineering and organizes the educational side of our program. He specializes in research and development of bioinstruments for measuring oxygen levels in blood and oxygen consumed by a patient to aid physicians in treating patients and for medical research. He develops improvements in an acoustical holography instrument for better imaging of internal body parts. He investigates the effects of microwave radiation on man to determine hazard levels of radiation and to help establish a scientifically sound safety level for the nation.

VIII. MICROCIRCUIT LABORATORY:

Dr. Robert Huber is the technical director. The Microcircuit Laboratory of the University of Utah is the best equipped and most strongly staffed Microcircuit Laboratory of any university in the United States. All aspects of the production of microcircuits are possible. Microcircuits are made by a photographic reduction process and further, by so-called photo-engraving. The original drawings of the electronic design of a microcircuit are reduced 500 times linear reduction, which amounts to 250,000 times area reduction. As a result, the entire inner works of a small computer, for example, can be built into a chip one-quarter inch squared.

A Large Scale Integrated Circuit

(2x actual size)



The Microcircuit Laboratory offers the possibility to interact with the nervous system - either the brain, medulla, nerves, carotid sinus or heart pacemakers. Using special arrays of electrodes, we can send signals into the brain such as will be used for the artificial eye and the artificial ear or derive signals from the brain, such as from the motor cortex to enervate a paralyzed limb.

In the coming years, microcircuits should be used in electrophysiology - as a matter of fact, we are manufacturing an electrode that has a preamplifier on it for Dr. Abildskov.* They should also be used in pacemakers. When used in artificial pacemakers, 25 percent of the power can be saved. They might find other applications, such as stimulation of the carotid sinus in the treatment of certain types of hypertension. Regardless of where they will be used, they must be made in a special laboratory aiming at biomedical applications since the high volume low unit profit industry of microcircuits cannot deviate to special techniques for physiological experiments. This facility is available at the University of Utah.

IX. <u>THE ARTIFICIAL EYE:</u> (Leader - Mr. William Dobelle)

We believe that it is possible to obtain images with two small television cameras and to transmit these images directly to the brain. It has been known for many years that if the brain cells in the occipital lobe are stimulated, the patient sees a light. It is the aim of the Artificial Eye Team in Utah to coordinate the image obtained by a television camera with the proper stimulation of the cells in the brain. If this succeeds, anyone, even without eyes or optic nerves, but with an intact optical cortex of the brain, will be able to get visual sensation which hopefully would be helpful for him. It would not be necessary to train such a person because the image that is created by stimulation of the brain cells will look like a recognizable pattern. The entire process has been simulated on a computer and on this basis, the Utah team is optimistic that it will be possible to create a visual prosthesis which will make it possible for a blind person to move around without bumping into other people. <u>An artificial ear</u> is being approached along the same lines.

* Electrophysiologist-Cardiologist, Univ. of Utah

To compress the television camera, computers and other devices required for the artificial eye (so small that a blind man can wear it without discomfort and so small that a part of it can be implanted inside the skull directly upon the visual cortex of the brain), it is necessary to make microcircuits.

X. INNERVATION OF PARALYZED LIMBS AND MOTIVATION OF ARTIFICIAL LIMBS:

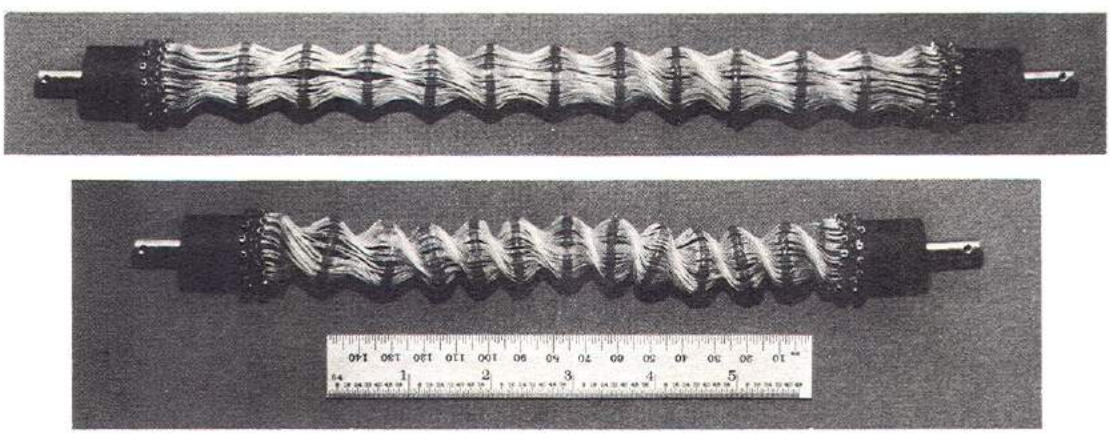
Equally exciting is the possibility that signals can be picked up from the motor cortex of the brain. Mr. Dobelle and his team have indeed demonstrated in a patient whose skull happened to be open for a surgical intervention, that the motor cortex of this man's brain "fired" everytime he opened his mouth. Everytime a person moves a limb or a muscle group in his body, the motor cortex of the brain fires. There is hope that this "firing" (electrical currents) can be picked up with specially built arrays of electrodes and that these signals can be used to either innervate nerves of paralyzed limbs or to induce motion in artificial arms or legs. It is speculated with considerable credibility that in the case of a person with a broken neck (or other transsection of the spinal cord), signals directly obtained from the brain can be used to induce purposeful movement of paralyzed or artificial limbs.

XI. ARTIFICIAL ARM:

To fully exploit the possibility of artificial limbs, it is probably wise to first take a step to merely extend the present state of the art of making artificial limbs. Dr. Steve Jacobsen, a former associate of ours, has joined us again and is in charge of the artificial arm project. He has done three significant things:

1. He has built better electrodes to pick up the myo-electric signals from the shoulder muscles of an amputated arm stump.
2. He has invented a new type of artificial muscle which is light-weight, very strong, and can be precisely controlled electrically.
3. He has worked out mathematically, the theory of movement of an artificial arm using the signals from the shoulder muscles of the stump.

This promises to give better controlled motion of the arm than was heretofore possible with the use of the Temple arm, the Boston arm and other presently available devices.

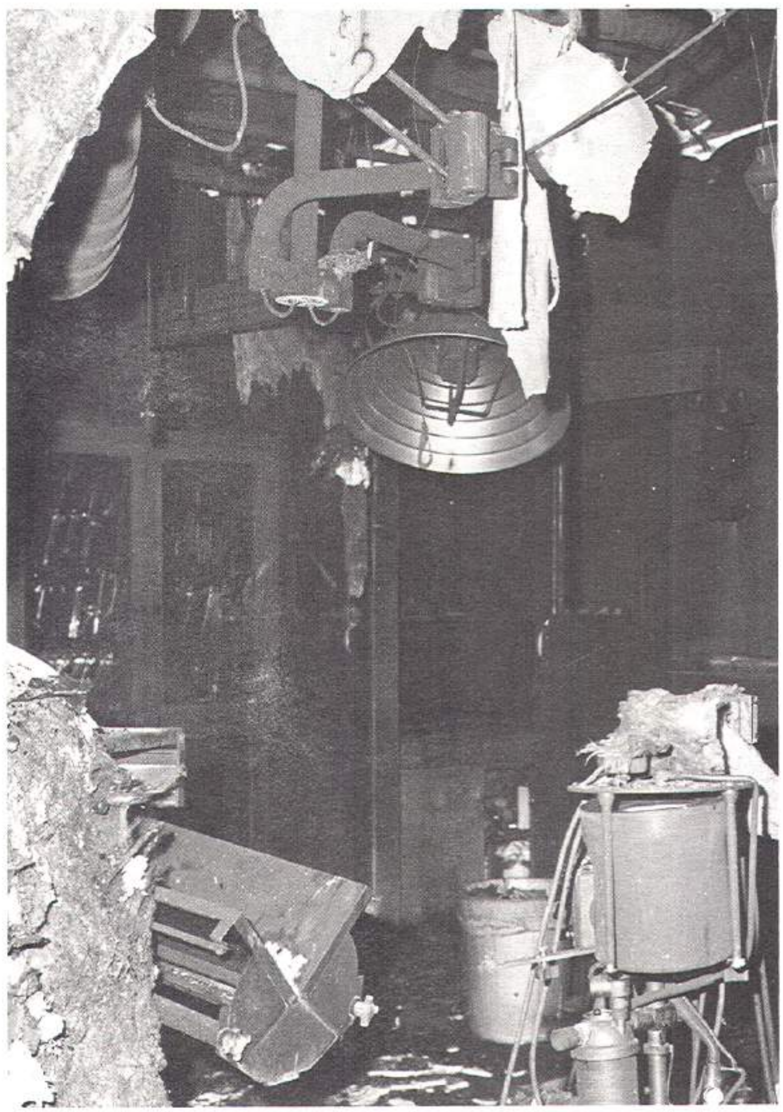


Prosthetic Actuator in extend and contracted positions

XII. THE FIRE

On May 5, 1973, our main building (512) burned out. The extent of the damage was $310,948. No personal injuries occurred. This building contained our operating rooms, heart testing rooms, mold rooms, and our most expensive equipment. Our collection of artificial hearts since 1957 was lost. The molds of the newest, most promising heart (Jarvik Heart) were salvaged. Our engineering laboratory, the artificial kidney section, and the microcircuit laboratory were not damaged.

Surgery Suite



Clean-up after the fire

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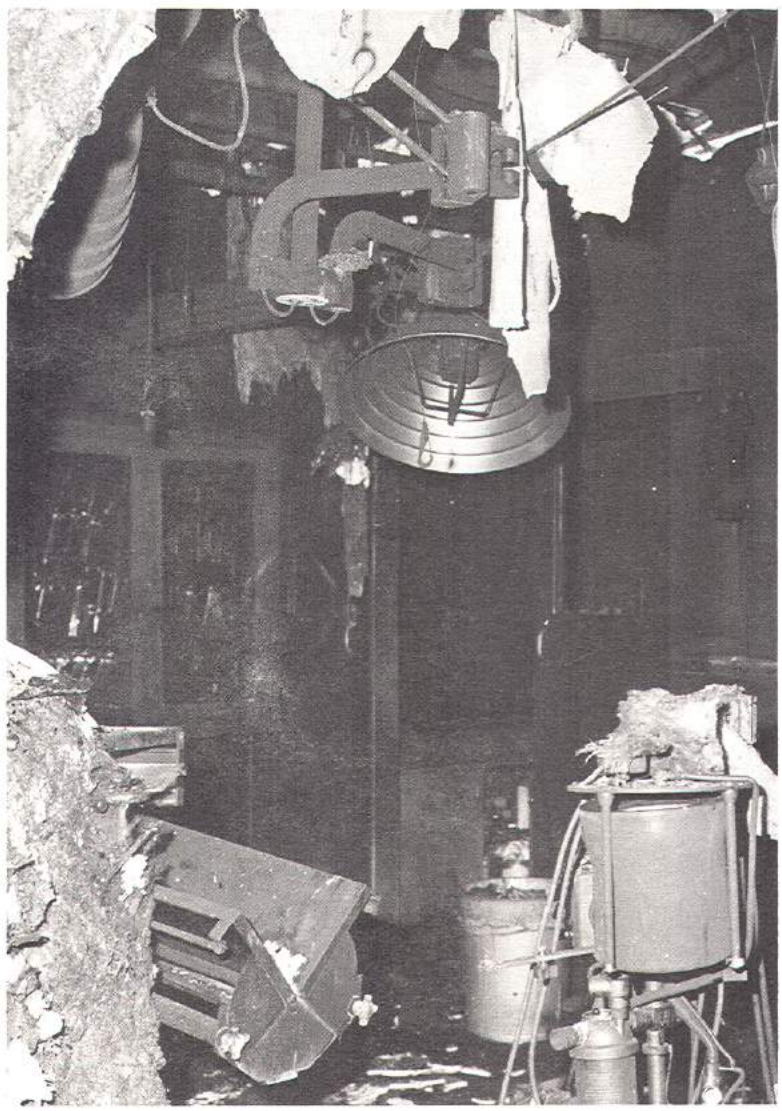
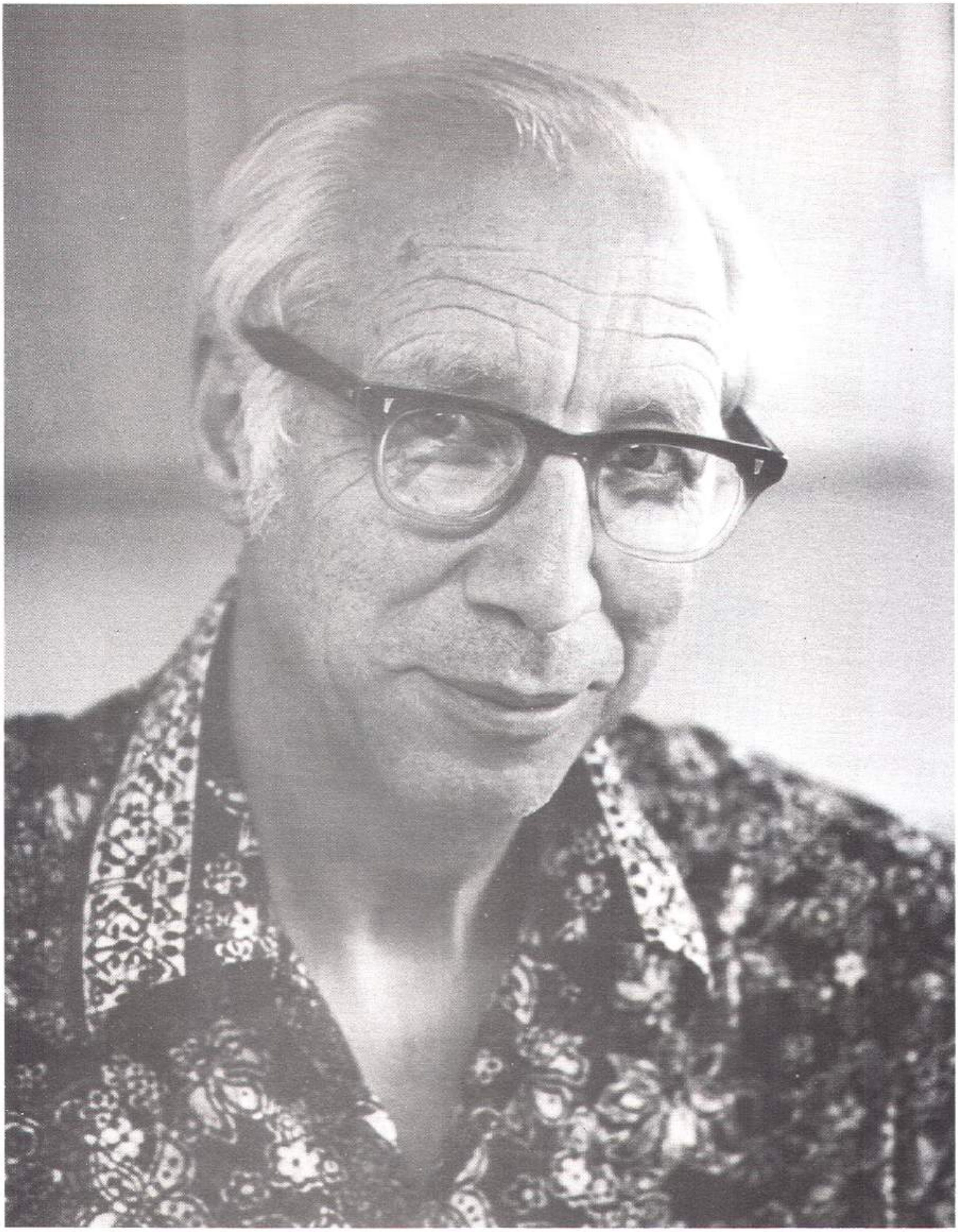


Clean-up after the fire

XIII. INTRODUCTION TO SCIENTIFIC PERSONNEL - BIOGRAPHICAL SKETCHES

One of the great potentials of the Institute for Biomedical Engineering of the University of Utah is the diversification of the people who are employed by it. Most of them convene at the 8:00 a.m. daily morning conference in the general conference room in Bldg. 518. One of the employees gives a presentation so that gradually, all the members of the Institute become aware of the work and potential of others. Since there are surgeons, an internist, an anesthesiologist, nephrologists, a veterinarian, physiologists, engineers (electrical, mechanical, industrial and chemical), physicists (theoretical and practical), chemists, polymer-chemists and a metallurgist among the members of the Staff of the Institute, it is a very able and most exciting group. Most of them hold joint faculty appointments in their basic discipline.



W. J. KOLFF, M.D., Ph.D.

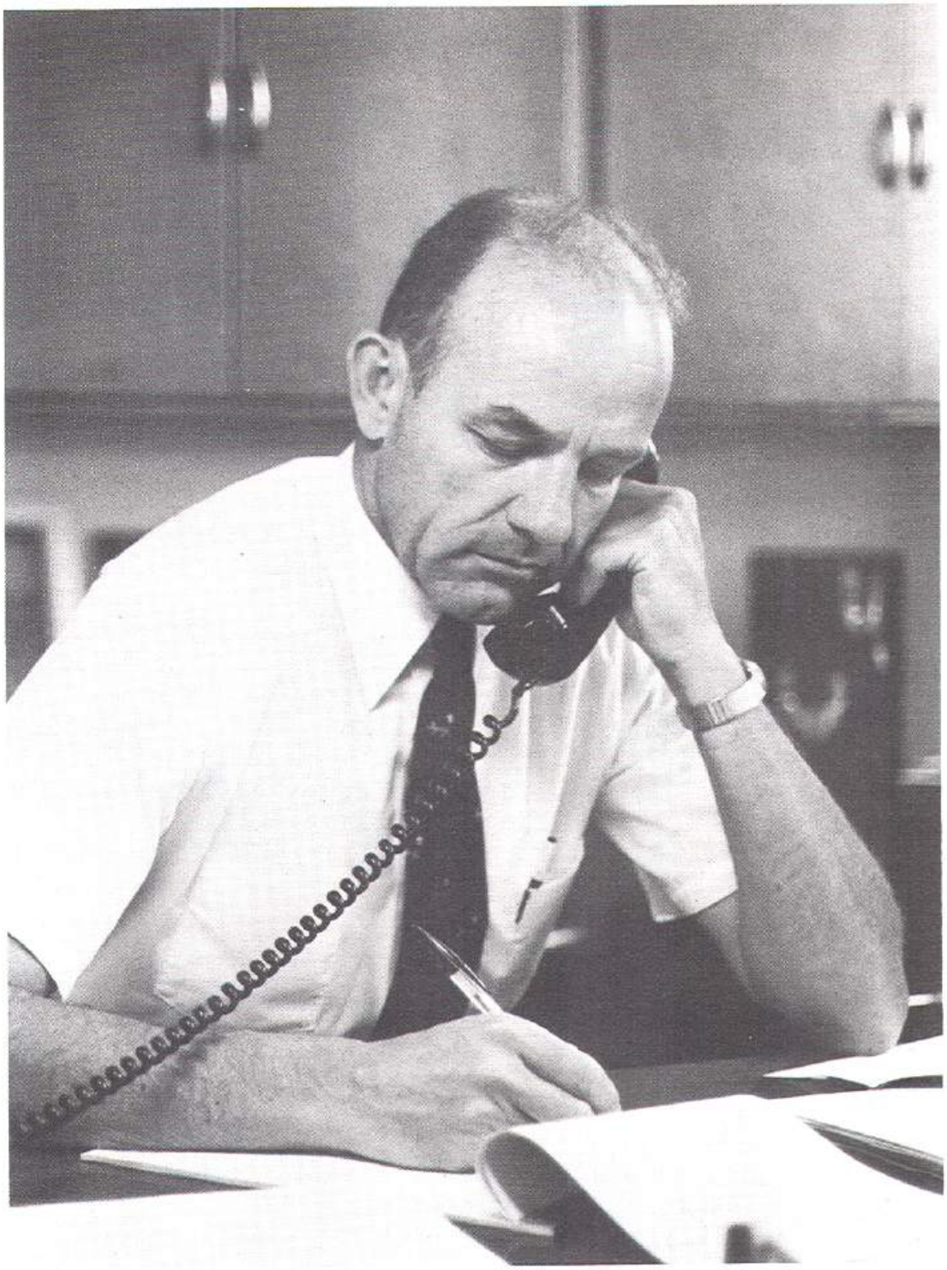
Willem J. Kolff, M.D., Ph.D. is an internationally known internist and the inventor of a life-giving machine - the artificial kidney - a machine which he developed under the very difficult circumstances of the German occupation of his native Netherlands. Materials for his work were hard to obtain and had to be procured without the knowledge of the Germans. The first person to be saved by the artificial kidney underwent treatment in 1945. There are now more than 4,000 artificial kidneys in use in the United States alone.

First in the Netherlands and after 1950 at the Cleveland Clinic, Dr. Kolff pioneered in the development of the heart-lung machine and in the procedure of elective cardiac arrest which allows much more effective heart surgery than was ever possible previously. In 1961, Dr. Kolff and his colleagues developed the intra-aortic balloon pump which is now the most widely used cardiac assist device.

For these and other accomplishments, Dr. Kolff has received numerous awards and honorary degrees, including the Landsteiner Silver Medal, the Cameron Prize awarded by the Univ. of Edinburgh, the Golden Plate Award of the American Academy of Achievement, the Leo Harvey Prize and the John Phillips Memorial Award of the American College of Physicians.

In 1967, Dr. Kolff joined the University of Utah where he is now Professor of Surgery and Head of the Division of Artificial Organs, Dept. of Surgery in the College of Medicine. He is also Research Professor of Engineering and Director of the Institute for Biomedical Engineering.

Under his direction, the Division of Artificial Organs has developed rapidly. It now includes internists, chemical engineers, surgeons, physicists, mechanical engineers, physiologists, anesthesiologist, chemists, metallurgist, mathematicians, electrical engineers, computer scientists, veterinarian and hematologists working on such projects as artificial hearts, an artificial eye (to include a television camera and an ultra-miniature computer in the size of a human eyeball), improved artificial kidneys, artificial ears, artificial tracheas and a number of surgical techniques and devices. It is a testament to Dr. Kolff's energy and skill as an administrator that he manages to keep all of these projects and people working smoothly together. One method that is useful for this purpose is a morning conference every morning of the week where one of the members of our group gives a brief report on his work, followed by a discussion in which everyone is welcome to participate. Dr. Kolff manages to combine a critical, analytical mind with a willingness to allow his colleagues to follow, sometimes unorthodox, methods or ideas. The result is an exciting scientific atmosphere which has been quite productive. For example, our laboratory is making good progress toward the development of a completely implantable artificial heart, and we have kept a calf alive for 18 days after the removal of his natural heart - a world record.

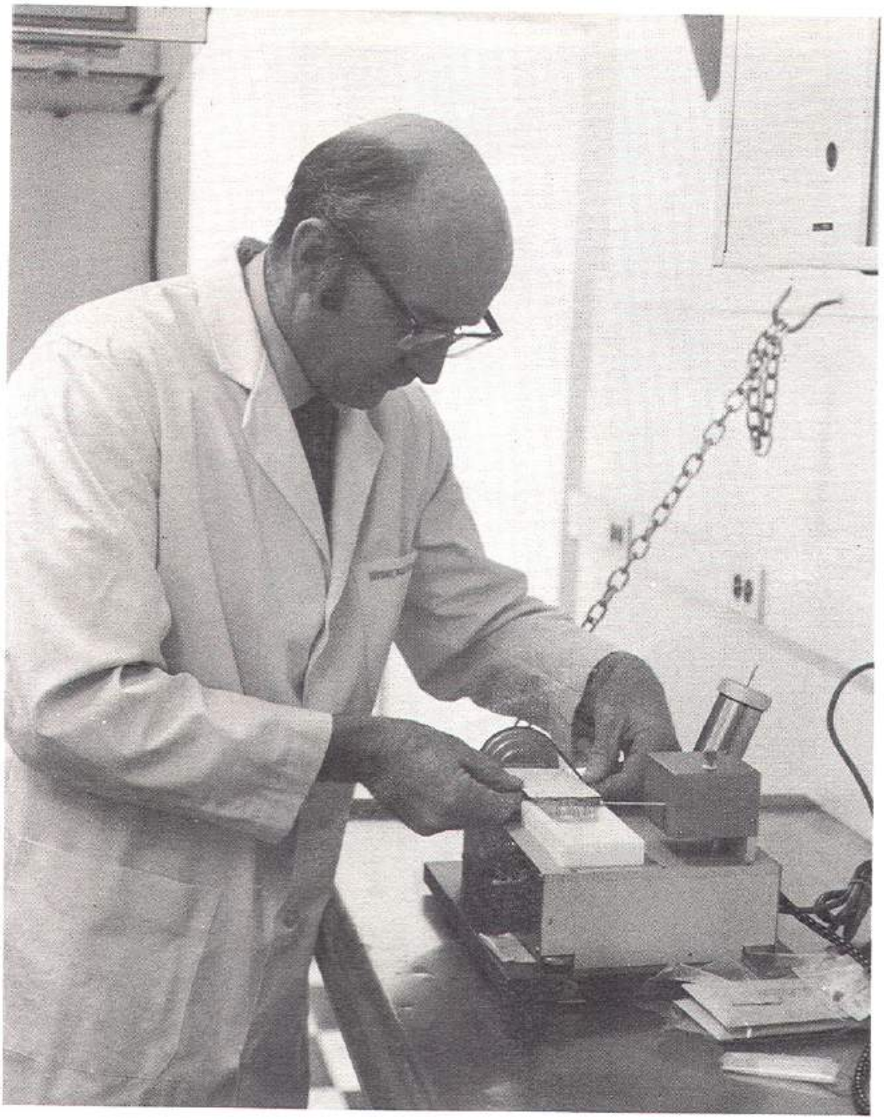


JOHN WARNER, B.S.

John Warner is the administrator of the Division of Artificial Organs and the Institute for Biomedical Engineering with responsibilities for purchasing, inventory, physical facilities, financial resources, and personnel and payroll administration. His is a large and complicated task since, as one example, physical facilities includes the Dialysis Center which is located in the main building of the University Hospital, the microcircuit laboratory has their own building in downtown Salt Lake City, the surgery is carried on at the old St. Mark's Hospital, the engineers are located in Merrill Engineering Building, while the machine shop, prosthetics lab, and administration is located in Building 518 on the University campus. In his spare time, John Warner is also the organizer, leader, and guide for the Division's annual climb of Mt. Timpanogas and the semi-annual jeep expeditions to the canyonlands area in southern Utah.

DON OLSEN, D.V.M.

Calves are useful experimental animals, but they are not ideal patients. It takes an expert to deal with the many problems presented by a calf which has undergone major surgery. Dr. Don Olsen, by virtue of his training in veterinary medicine and seven years of clinical experience, is such an expert. He is responsible for obtaining healthy animals and maintaining them prior to surgery. He often assists during the surgery and has greatly improved the postoperative care of our animals. Since leaving his clinical practice, Dr. Olsen has done experimental work in the pathophysiology of pulmonary cardiovascular disease at the University of Nevada at Reno and has been the recipient of a four year fellowship in the Department of Pathology at the University of Colorado School of Medicine, where his Ph.D. work dealt with the biochemistry and neosynthesis of pulmonary surfactant. He is thus particularly well qualified to work on one of the persistent problems associated with artificial hearts - the shock lung or respiratory distress syndrome. Dr. Olsen, who first welcomes the calves to the Division of Artificial Organs when he purchases them, also bids them farewell when he conducts the postmortem and pathological evaluation of each experiment. He often serves as Acting Director of the Division of Artificial Organs during Dr. Kolff's absence.



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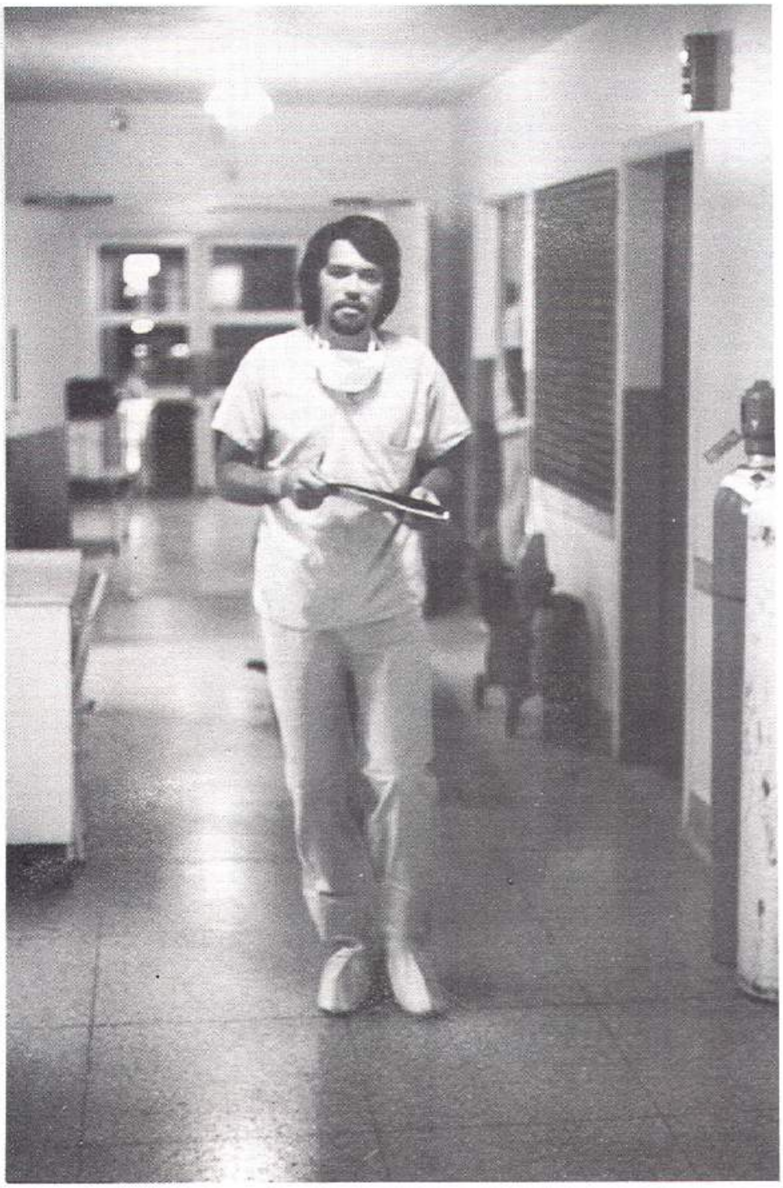
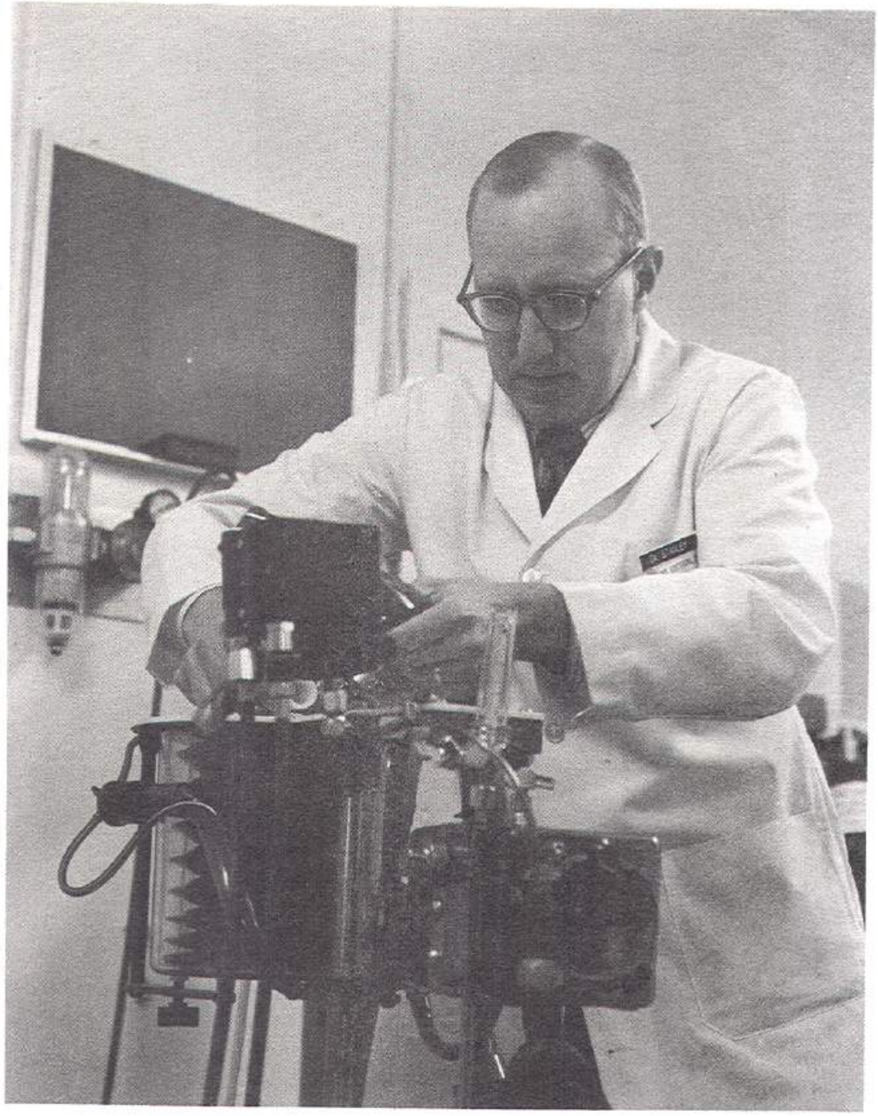


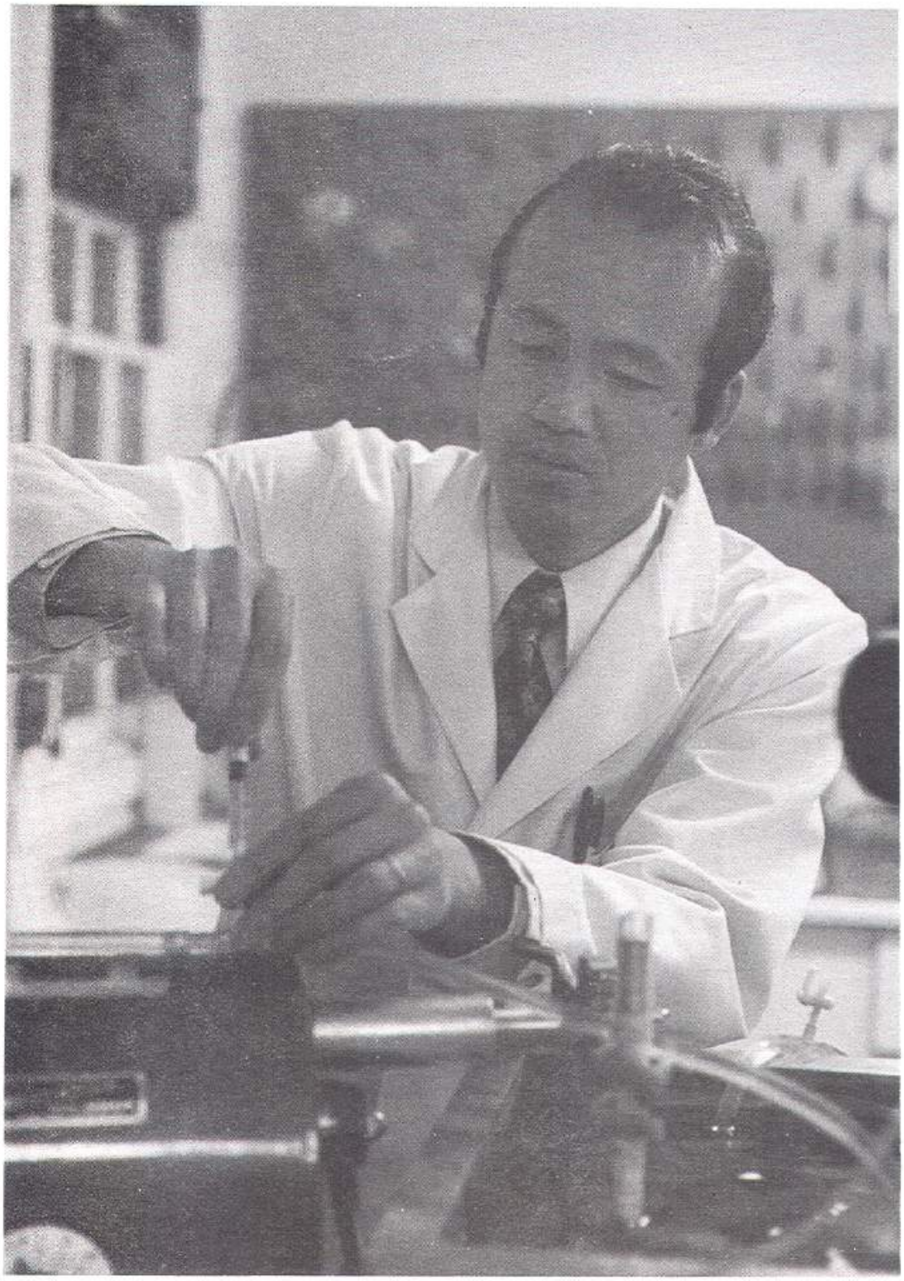
JAY VOLDER, M.D.

Dr. Volder, a surgeon trained in The Netherlands, serves as the chief surgeon in all of our total heart replacements and is often the principal investigator in such experiments. He is also responsible for two other series of experiments, the in vivo evaluation of new materials for A.V. shunts and extracorporeal recirculation experiments. The latter experiments consist of attaching two artificial ventricles to a calf's aorta while the natural ventricles are undisturbed. The artificial ventricles remain outside the animal's body where one beats and the other remains passive. This relatively simple procedure allows Dr. Volder and his colleague, Dr. Ed Hershgold, to evaluate the hematological effects of a number of materials that might be used to make artificial organs. In whatever time he has available after these projects, Dr. Volder occasionally gives recitals on his guitar, an instrument upon which he is quite accomplished.



TED STANLEY, M.D.

Dr. Stanley's interests and achievements cover such a wide area that to list them all would be to write a catalogue. Despite the variety of his interests, Dr. Stanley is not a mere dilettante, for his interests have led to solid achievements. He has been the principal author of 22 scientific papers. Since receiving his M. D. from Columbia University he has taken residencies in Surgery (University of Michigan Hospital) and in Anesthesiology (Columbia-Presbyterian Medical Center), and has served as staff anesthesiologist at Lackland Air Force Base. He designed the first artificial anal prosthesis and the first successful artificial urinary bladder. The latter achievement established that regeneration is possible in the urinary tract. At present he is continuing to work on numerous projects, including the effect of various anesthetics on pulmonary function, the measurement of effective cardiac output and other problems in basic pharmacokinetics and cardiopulmonary physiology, to which an animal with an artificial heart lends itself. Dr. Stanley divides his time between the Division of Artificial Organs and the Division of Anesthesiology at the University of Utah Hospital.

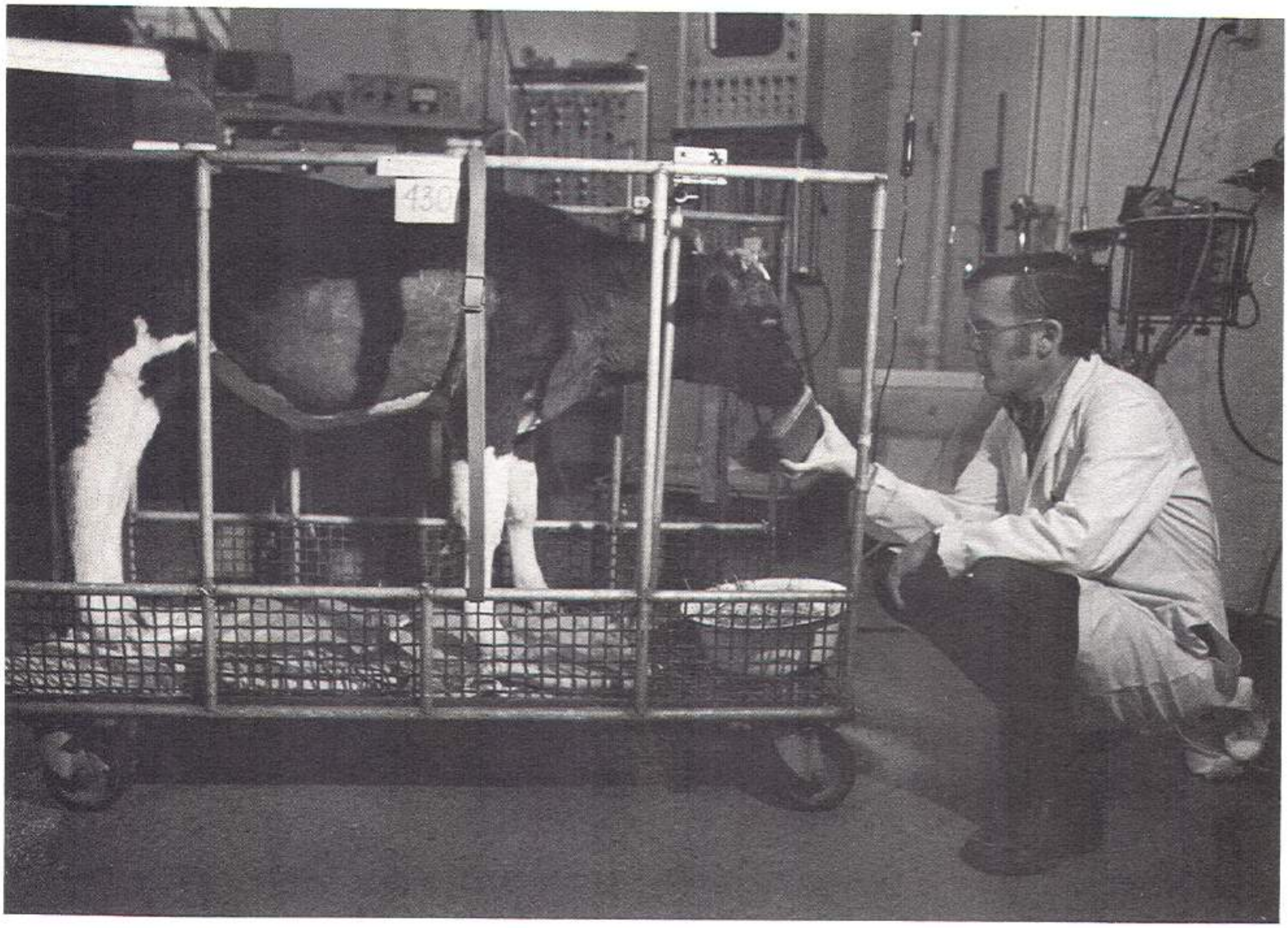


NOBUTOSHI IMAIZUMI, M.D.

For reasons that are not entirely clear, liver failure is a more common medical problem in Japan than in the United States. Thus, it is appropriate that our attempts to develop an artificial liver are led by a visiting Japanese surgeon, Dr. Imaizumi. At present, he is concentrating on methods of preserving and perfusing livers removed from animals. To do this, Dr. Imaizumi uses a variety of approaches, such as freeze-drying livers, then measuring the ability of the liver cells to carry on their normal metabolic functions. Dr. Imaizumi is also interested in liver transplantation.

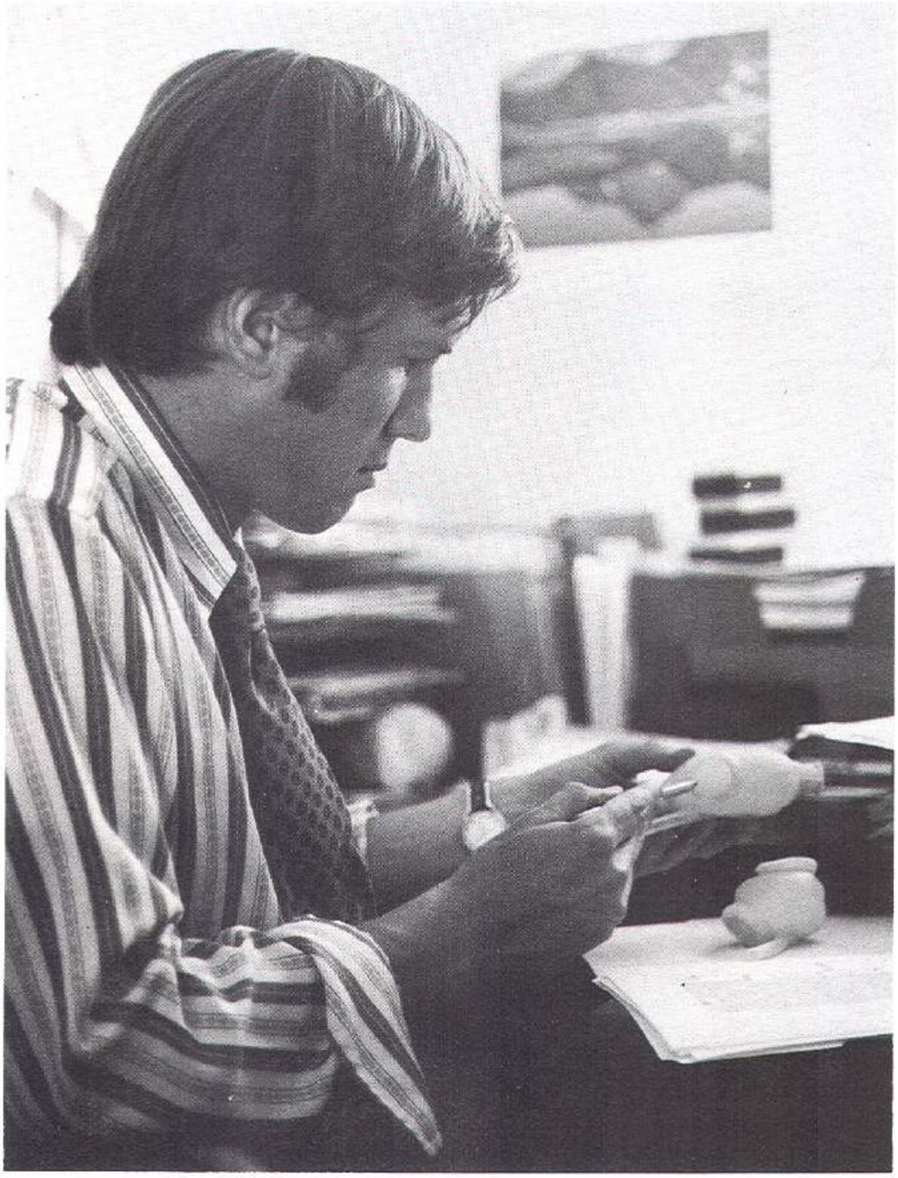
HARTMUT OSTER, M.D., Ph.D.

Dr. Oster is visiting the Division of Artificial Organs for two years from his home in Germany where he received his M.D. and Ph.D. from Marburg University Medical School. In Germany, he participated in pioneering efforts at liver transplantation. Since he has been in Utah, he has concentrated on the artificial heart. He has manufactured a number of hearts. The first total heart replacement experiment in which he served as principal investigator still holds the world record for the length of time that an animal has lived with a total artificial heart.



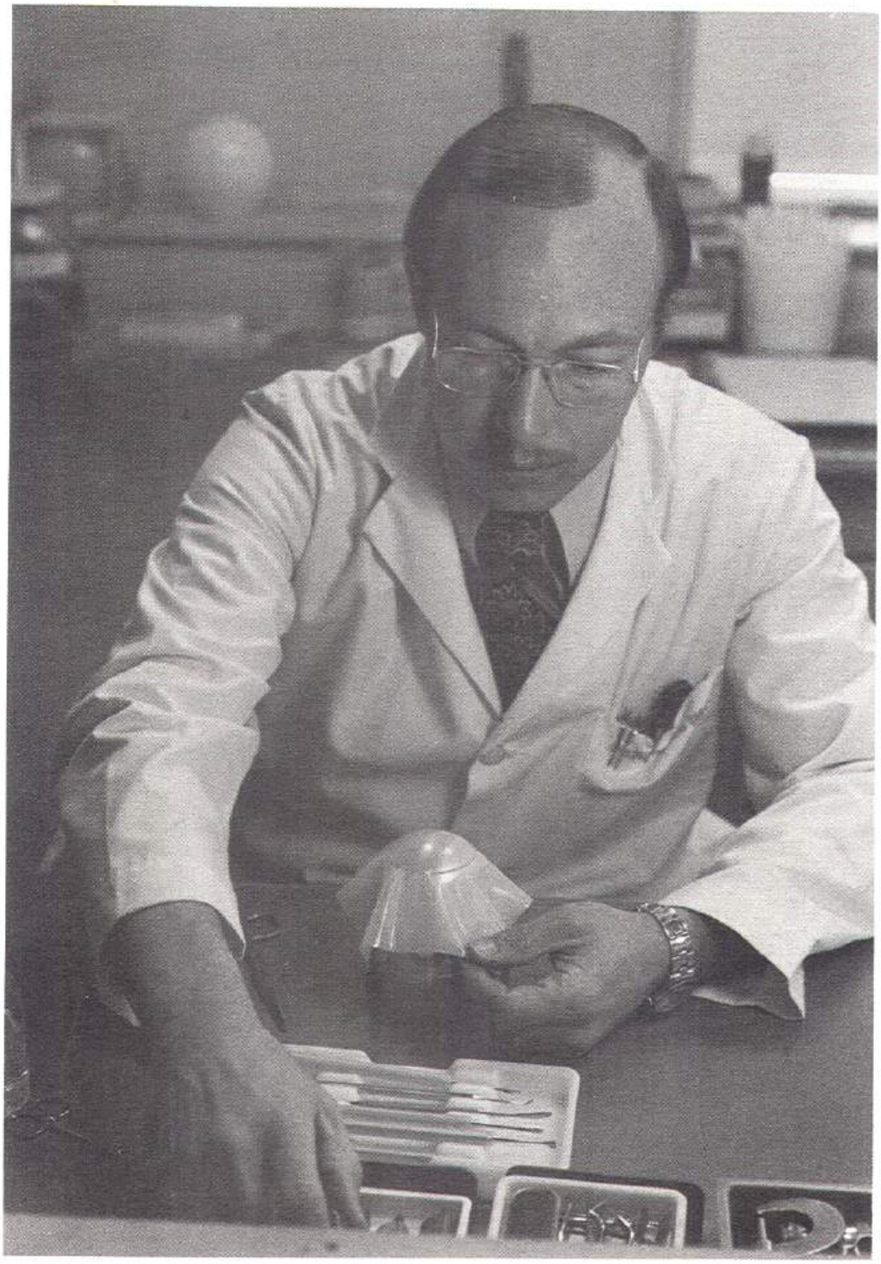
JOHN LAWSON, Ph.D.

John Lawson was contentedly working on a Ph.D. in Middle Eastern history when he took a part-time job helping our staff with the postoperative care of calves which had undergone total heart replacement. He quickly became fascinated with the complexity of the challenges faced by researchers in this area. Although he eventually completed his studies in history, he found himself devoting his time to the study of medieval Latin and Arabic writers and more time to developing his skills in such techniques as endotracheal intubation and gavage, and to proficiency with such laboraotry equipment as the flame photometer, the Radiometer blood gas machine, the Sanborn recorder etc. He is now head of our intensive animal care unit and is responsible for the training, scheduling, and supervision of the twenty or so people who take care of our animals. He also works as an editorial assistant and in the prosthetics lab.



JEFFREY PETERS, Ph.D.

Dr. Peters began working on cardiac assist devices while completing his Ph.D. in Physiology at Baylor College of Medicine in Texas. Dr. Peters has the unique distinction of being an Assistant Research Professor of Surgery at the University of Utah College of Medicine where he is also a fourth year medical student. He is particularly interested in the development of an artificial atria with compliant inner walls and has designed several versions which are quite promising. These artificial atria are designed to prevent the compression of the great veins of the heart and to serve as reservoirs, providing blood for the pumping ventricles. Dr. Peters has also developed a system for measuring the amount of blood damage caused by artificial hearts, and he has used the system to evaluate ten different artificial hearts developed at various laboratories. He is enthusiastic about the opportunities for basic cardiovascular research using the artificial heart.



TOM KESSLER

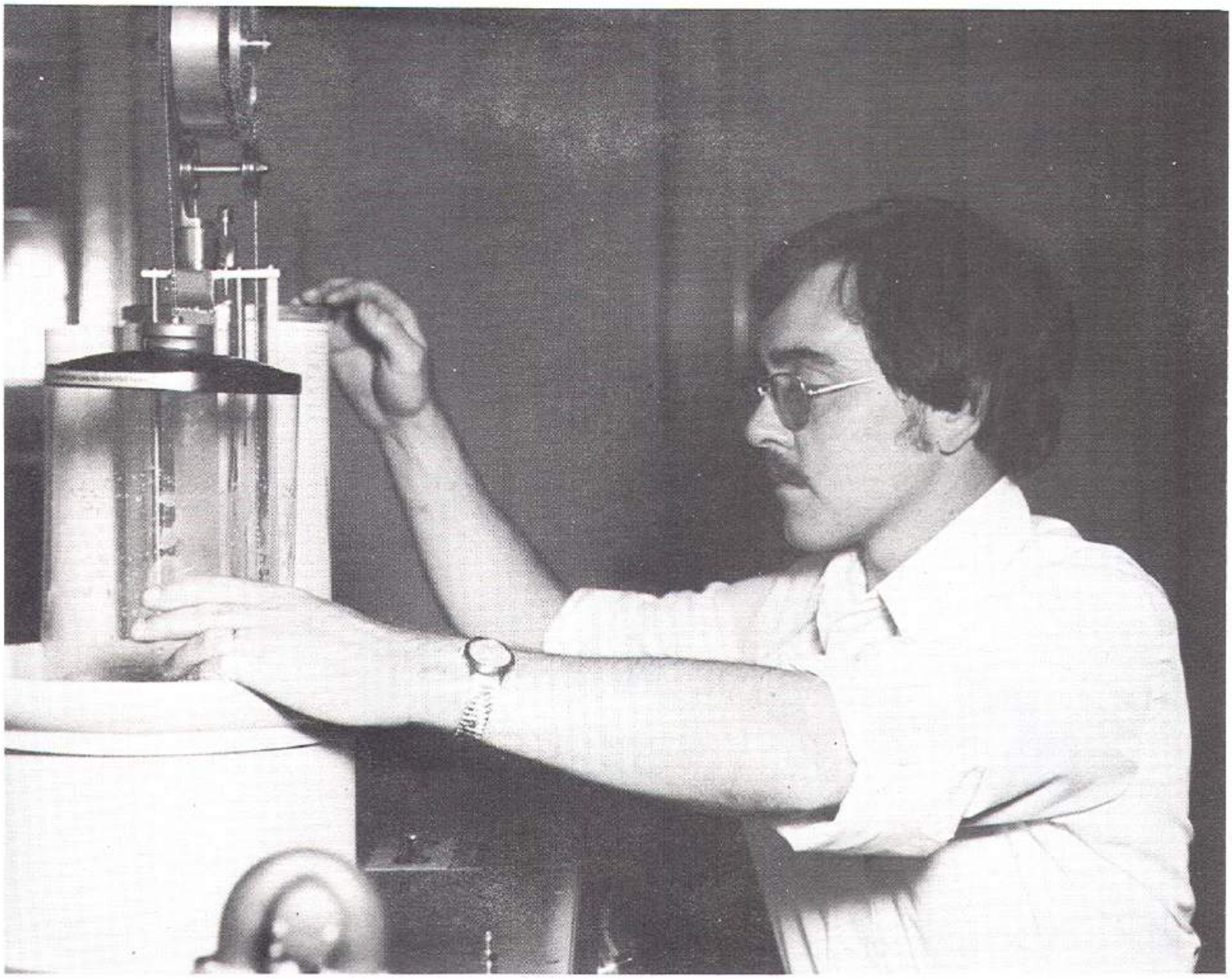
Mr. Thomas R. Kessler studied biology at Western Reserve University in Cleveland and served as a dental technician for four years in the Navy. In the Navy, he was trained in the art of mold making and in the manufacture of various dental prostheses. He is presently in charge of our prosthetics laboratory where he and his staff make dozens of items each day, ranging from artificial hearts to artificial tracheas. Mr. Kessler's talents give our laboratory the capability to produce nearly any item that is not yet manufactured on a commercial basis and thus, greatly extend the range of experiments that we can conduct. In the course of his work, he has become an expert on the physical properties of a wide variety of materials, particularly plastics, resins and rubber.

ROBERT JARVIK, M.S.

Robert Jarvik has always had two strong interests which at first seemed fairly incompatible. One interest was medicine, which he perhaps picked up from his father who is a physician and surgeon. The other interest was in design and art, particularly three-dimensional art. He began his collegiate career in architecture, but soon changed to a zoology major while continuing to take as many art courses as he could. After graduating from Syracuse University, he attended medical school at the University of Bologna. During vacations from medical school, he began to combine his two interests by designing surgical instruments. One of these was an automatic ligating instrument for which he has a patent and which may soon be produced by a medical instrument company. This work led to a fellowship in biomechanics at New York University, from which he received his M.A. in 1971. He then joined the Division of Artificial Organs where he has designed a number of artificial hearts, including one, currently our most successful model, which is the first artificial heart able to maintain normal venous pressures in experimental animals. He is continuing to develop and refine this artificial heart, as well as a mechanical heart designed to be used with a small atomic energy engine during the time that he can spare from his studies at the University of Utah Medical School.

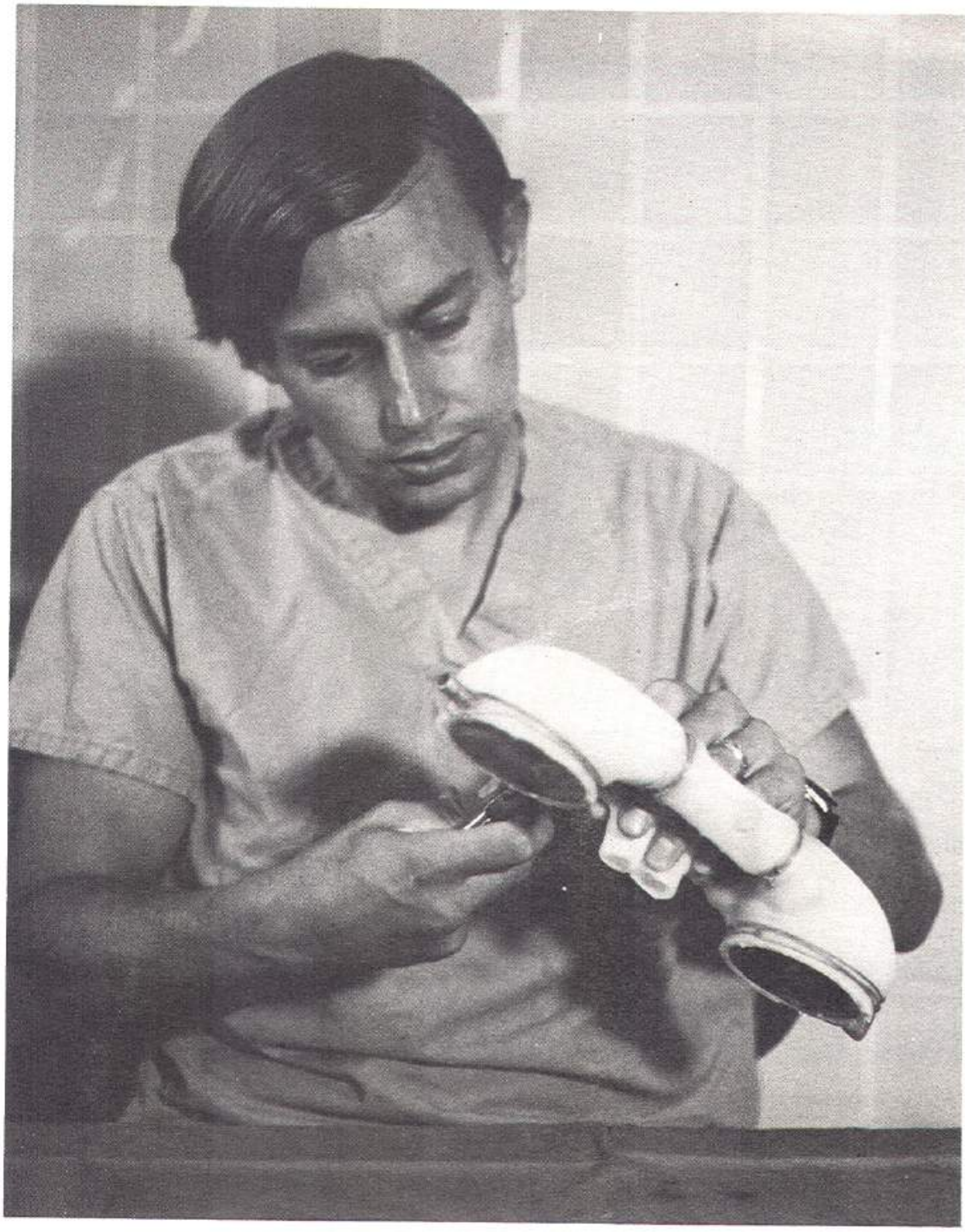
NEIL EASTWOOD

Neil Eastwood has been with the Division of Artificial Organs since its earliest days at the University of Utah. He began as our heart-lung bypass technician, but his years of experience with operating room procedure and with the equipment, both in the operating room and the clinical laboratories, have been utilized in a number of areas. He is in charge of our operating room and has filled every position in the operating room, from surgeon to calf sitter. He is also as proficient with a rod and reel as he is with the Bird respirator and there are few areas in Utah or neighboring states where he has not been fishing.



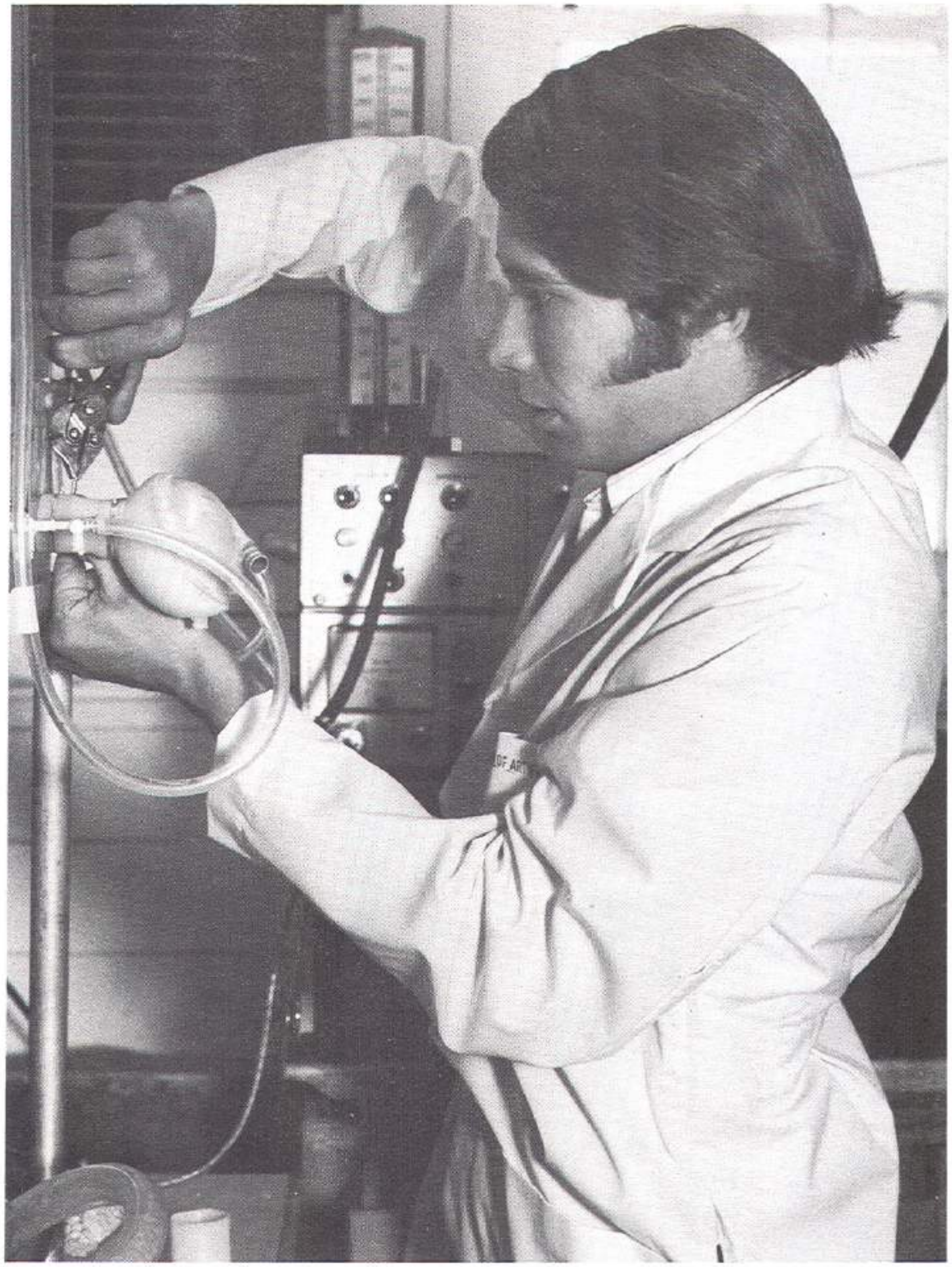
LEE SMITH, M.S.

Lee Smith has a B.S. in Electrical Engineering and an M.S. in Materials Science from the University of Utah. As is the case with many others in the Division of Artificial Organs, he is quite versatile. For his Master's thesis on cell adhesion, he had to build his own glow discharge chamber. He has recently built a larger version of the same device for our division which we now use to clean the surfaces of such objects as artificial hearts. He is also in charge of the pulmonary function tests on our experimental animals, another task for which he is well qualified since he is a registered cardio-pulmonary technologist.



MIKE NIELSEN, B.A.

Mike Nielsen is the Nielsen family representative on our operating room staff. As is the case with many of the members of our Division, he is quite versatile. He often assists in surgery and in autopsies. When he is not taking part in the surgery he often runs the heart-lung bypass machine or administers the anesthetic. Furthermore, he is one of the principal investigators in two series of experiments - (1) the recirculation experiments for which he designs the circuits and takes care of the postoperative management of the experimental animal and (2) the pulmonary hypertension experiments where the effect of induced pulmonary hypertension is studied.

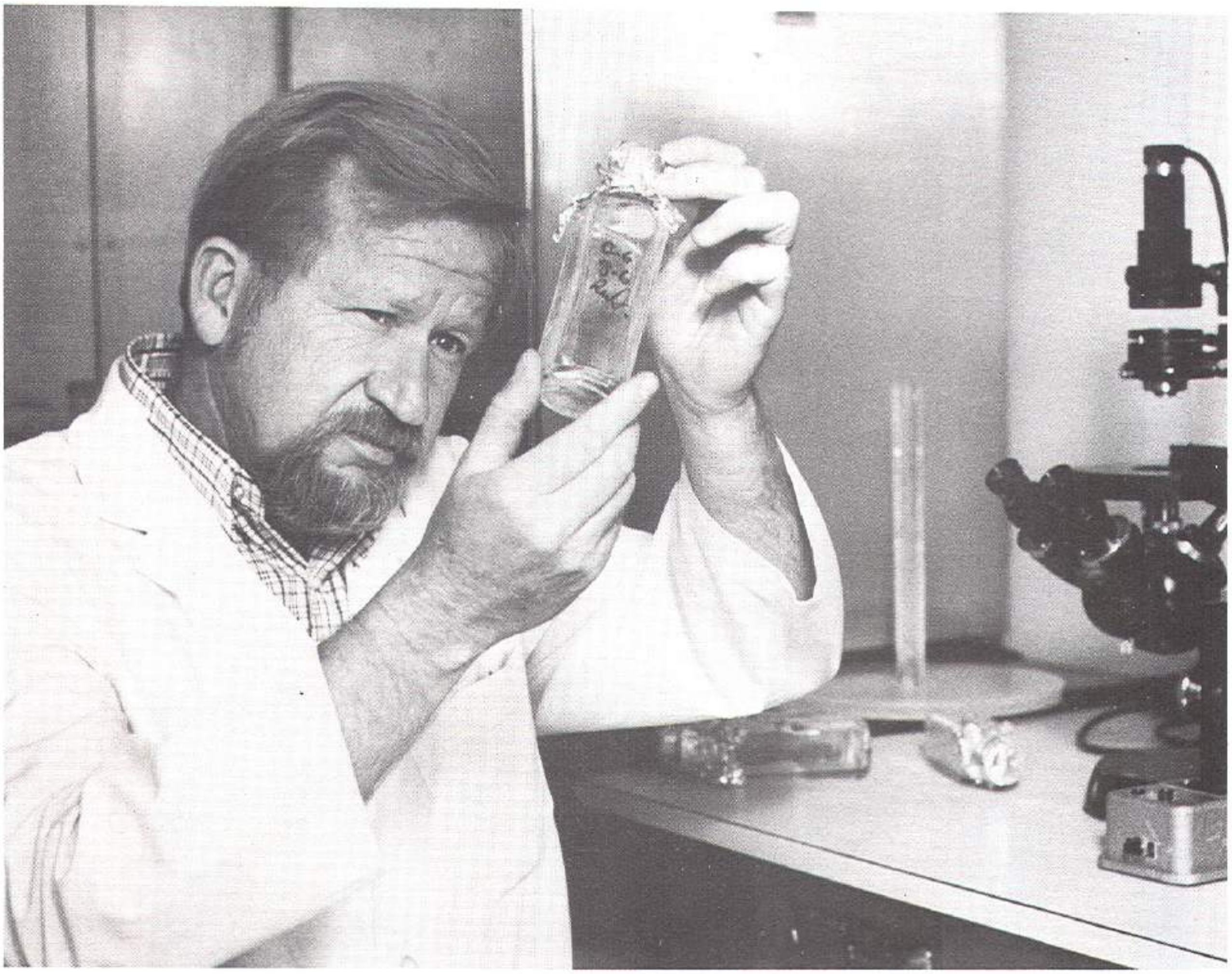


STEVE GREENHALGH, B.S.

Steve Greenhalgh is a mathematician who is responsible for testing our artificial hearts before implantation. Since all of our artificial hearts are hand made, each one has its own individual characteristics. In order to calculate cardiac output at the various venous and arterial pressures which might occur after implantation, the hearts are tested on a mock circulation loop, and Steve Greenhalgh draws the curve of performance for each heart. The expertise that he has attained in running the mock circulation systems has also been put to use in an extensive series of hemolysis tests using artificial hearts produced by a number of different laboratories in the United States. Mr. Greenhalgh is also a member of our surgical team where he is responsible for the heart driving system during the implantation process.

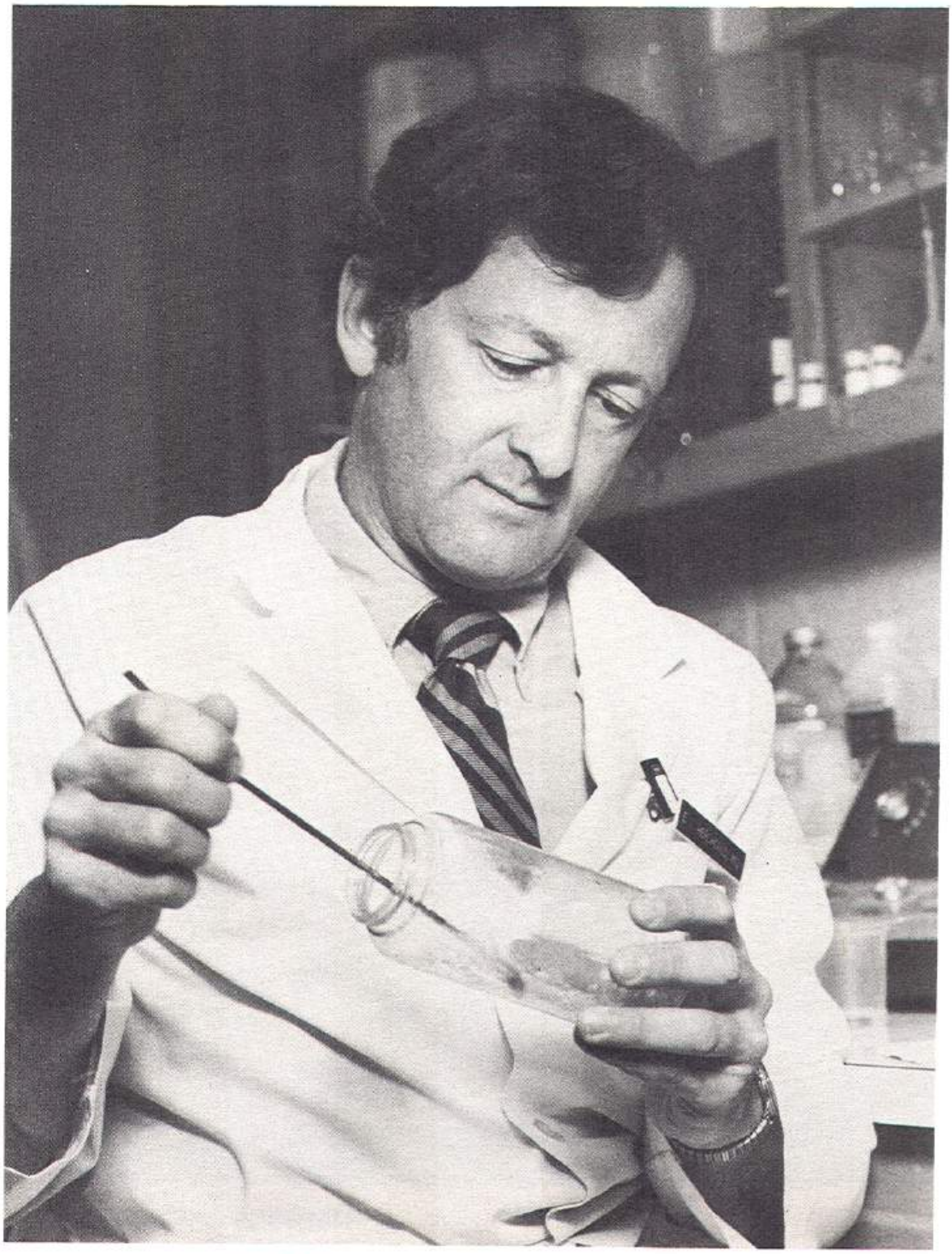
WALTER ROHLOFF

Walter Rohloff was trained as a tool and dye maker in his native Germany. When he immigrated to this country, he found work as a machinist in the maintenance machine shop at the University of Utah. In 1968, he moved to the Division of Artificial Organs. He and his staff are responsible for creating a wide variety of molds, devices, parts and equipment, everything from the metal portions of the artificial hearts to metal stalls for our animals. Mr. Rohloff is also one of the Division's most ardent basketball players despite the fact that he had never played the game before his fortieth birthday.



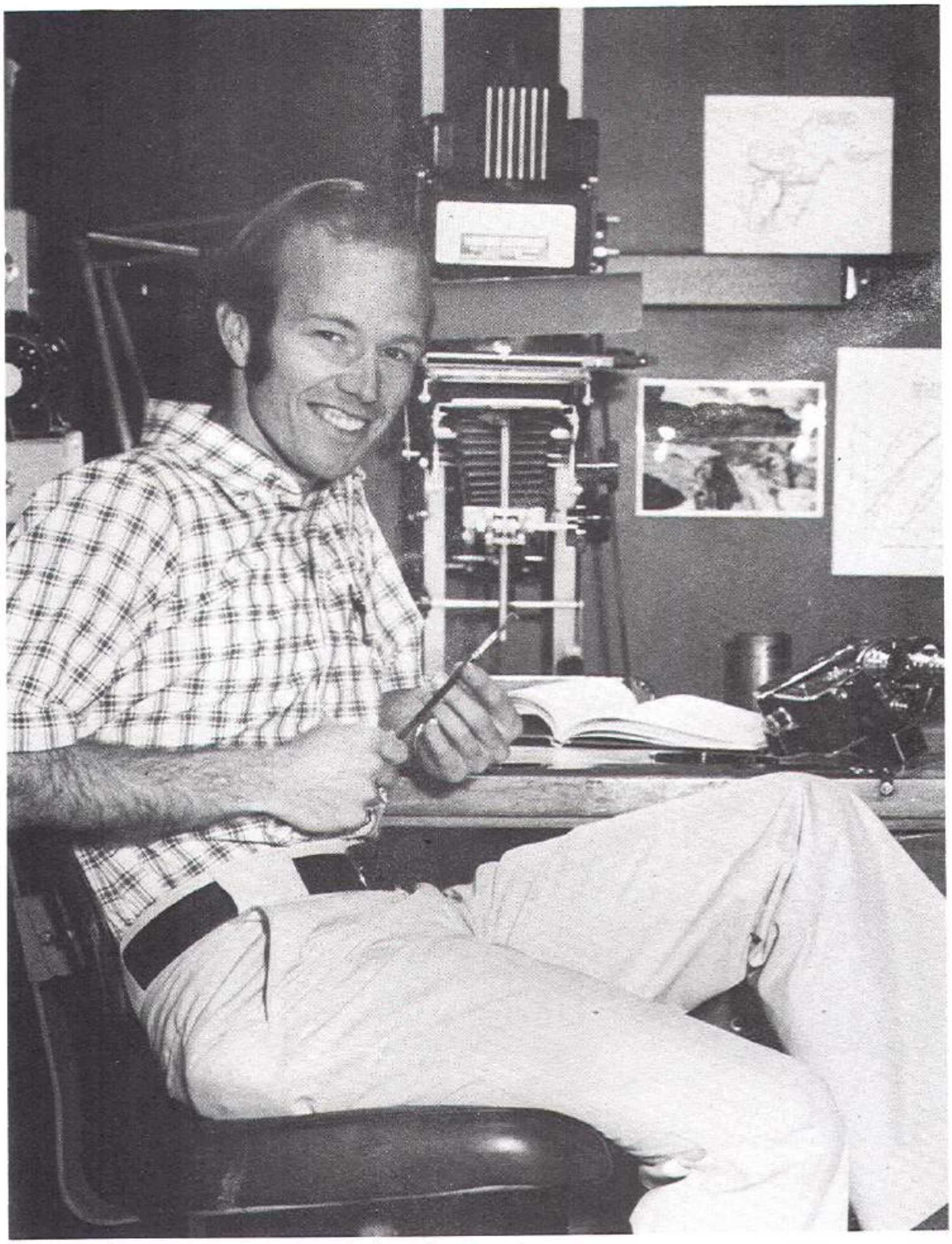
DOUGLAS HILL, Ph.D.

Dr. Douglas Hill is the Director of the Department of Microbiology at the University of Utah. He is assisting in our efforts to find a surface for our artificial hearts which will not damage blood. His approach is to culture embryonic cells onto the surface of the heart which, hopefully, will create an artificial heart with a living surface.



EDWIN HERSHGOLD, M.D.

Dr. Hershgold has held appointments at Harvard, Tufts and Stanford University Medical Schools. He is presently an Associate Professor at the University of Utah Medical School. He is a hematologist who works closely with Dr. Jay Volder on extracorporeal recirculation experiments. He also serves as a consultant on our total heart replacements. He is particularly interested in coagulation problems and coagulation problems are often a stumbling block in work with artificial organs.

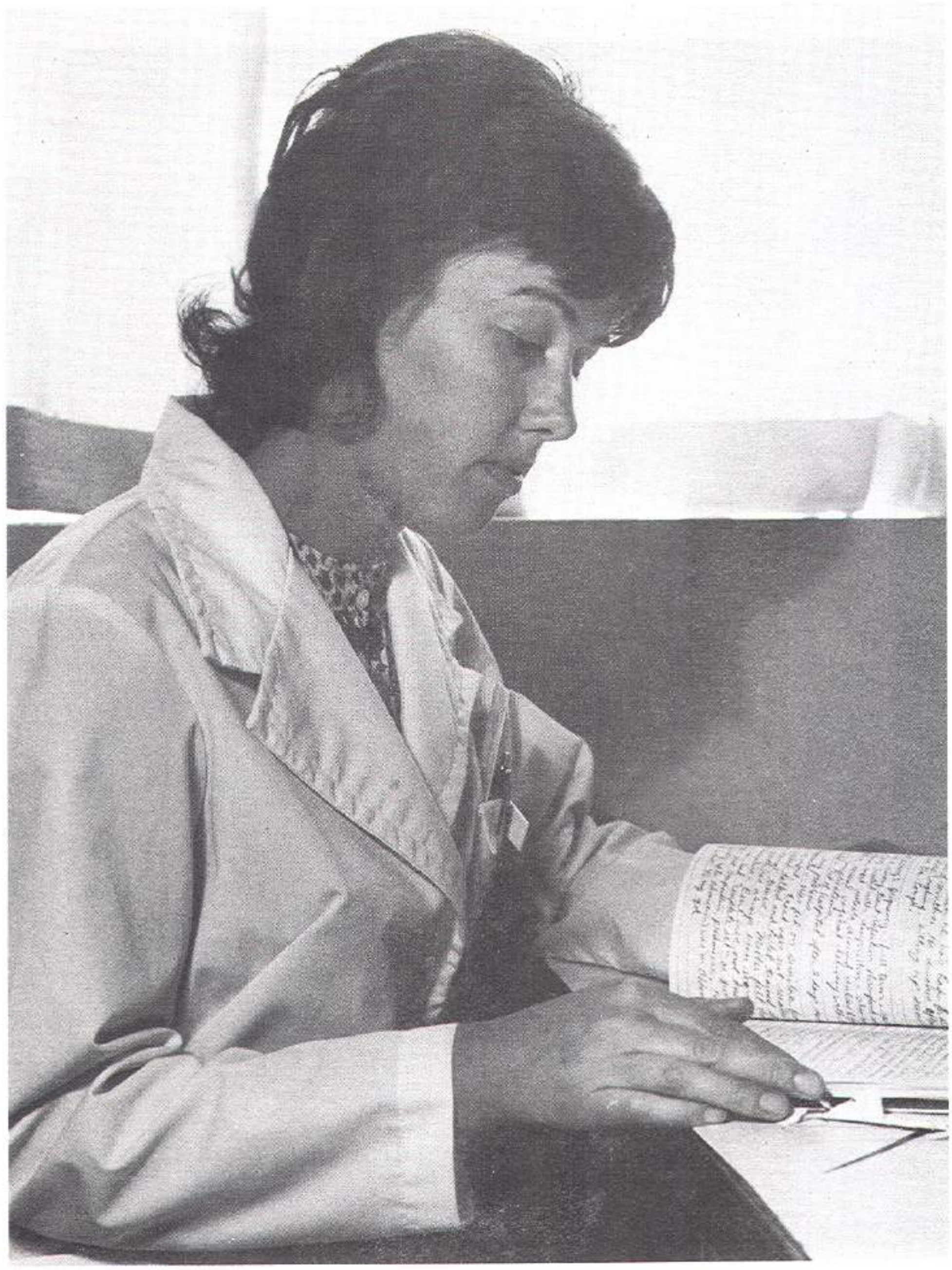


STEVE JOHNSON, B.S.

Scientific research is only of value if its results can be clearly and widely disseminated. This is usually accomplished either through lectures or by publication. In both situations, it would be almost impossible to communicate effectively without photographs or illustrations of some kind. Steve Johnson is equally proficient with pen and ink or Nikon and almost every publication or lecture by a member of the Division of Artificial Organs in the last few years has been more effective because of his skills.

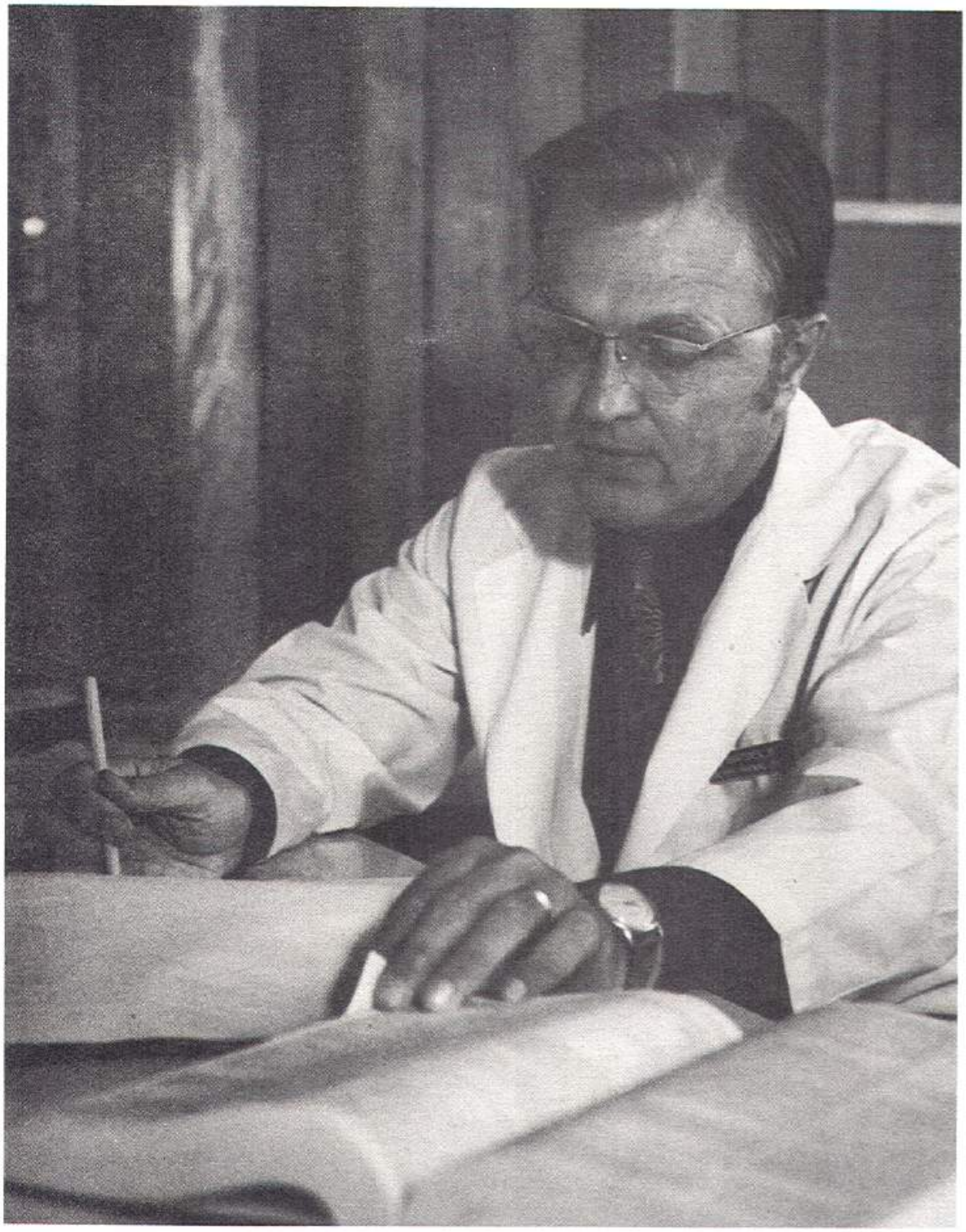
DIETZ VAN DURA

Dietz van Dura is the chief of Dialysis Services and Supervisor of the Home Dialysis Training Center. He also directs the activities of the Clinical Research Center Dialysis Unit for pre- and postkidney transplantation. Mr. van Dura is well known in his field and is presently second Vice President of the American Society for Extracorporeal Technology and serves on that society's executive board and board of directors. Furthermore, he is chairman of the Society's certification and education committee. He is also editor of the dialysis section of the Journal of Extracorporeal Technology.



ELISABET THOR, M.D.

Elisabet Atkin Thor, M.D. came to the University of Utah from her native Sweden, where her clinical practice was in Internal Medicine, for further training in Nephrology. While following this interest, she also serves as Acting Director of the Dialysis Center. She is one of the very few members of the Division of Artificial Organs who has no particular interest in research beyond the interest in using whatever advances in Medicine that are appropriate for her patients. She is completely wrapped up in the care of her patients and her interest is reflected in her great popularity among the patients and the respect of her colleagues in the Dialysis Center.



ERKKI HAAPANEN, M.D.

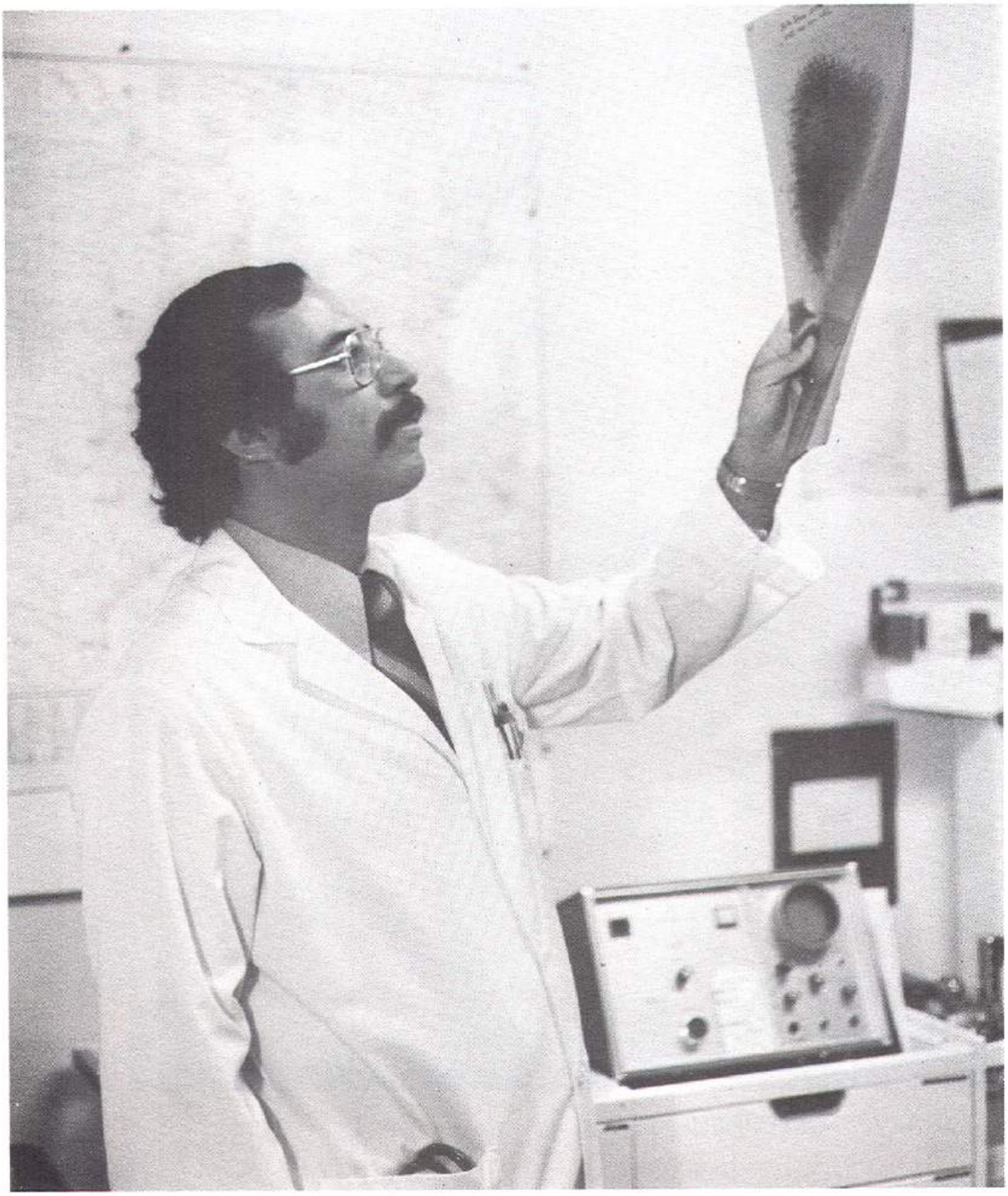
Erkki Haapanen, M.D. and the Division of Artificial Organs came to each other's attention because Dr. Haapanen was working on peritoneal lavage in his native Finland while the Division of Artificial Organs was working on the same technique in this country. Peritoneal lavage is a form of dialysis in which an amount of sterile water is pumped into the patient's peritoneal cavity where the peritoneal membrane allows the waste products to pass from a group of blood vessels to the water, whereupon the water is withdrawn and discarded. This form of dialysis has the great advantage of not bringing any foreign material into contact with the patient's blood. Dr. Haapanen has continued to work on this project, despite the large amount of time he devotes to the patients in the Dialysis Center.

PEG MILLER, B.A.

Mrs. Miller graduated from the University of Utah with a double major in Social Work and Psychology. She has worked as a medical social worker for seven years, first in the Psychiatry Department, then in Ob. and Gyn. and presently in the Dialysis Training Center, where she helps the patients faced with the formidable problems of dialysis treatment.

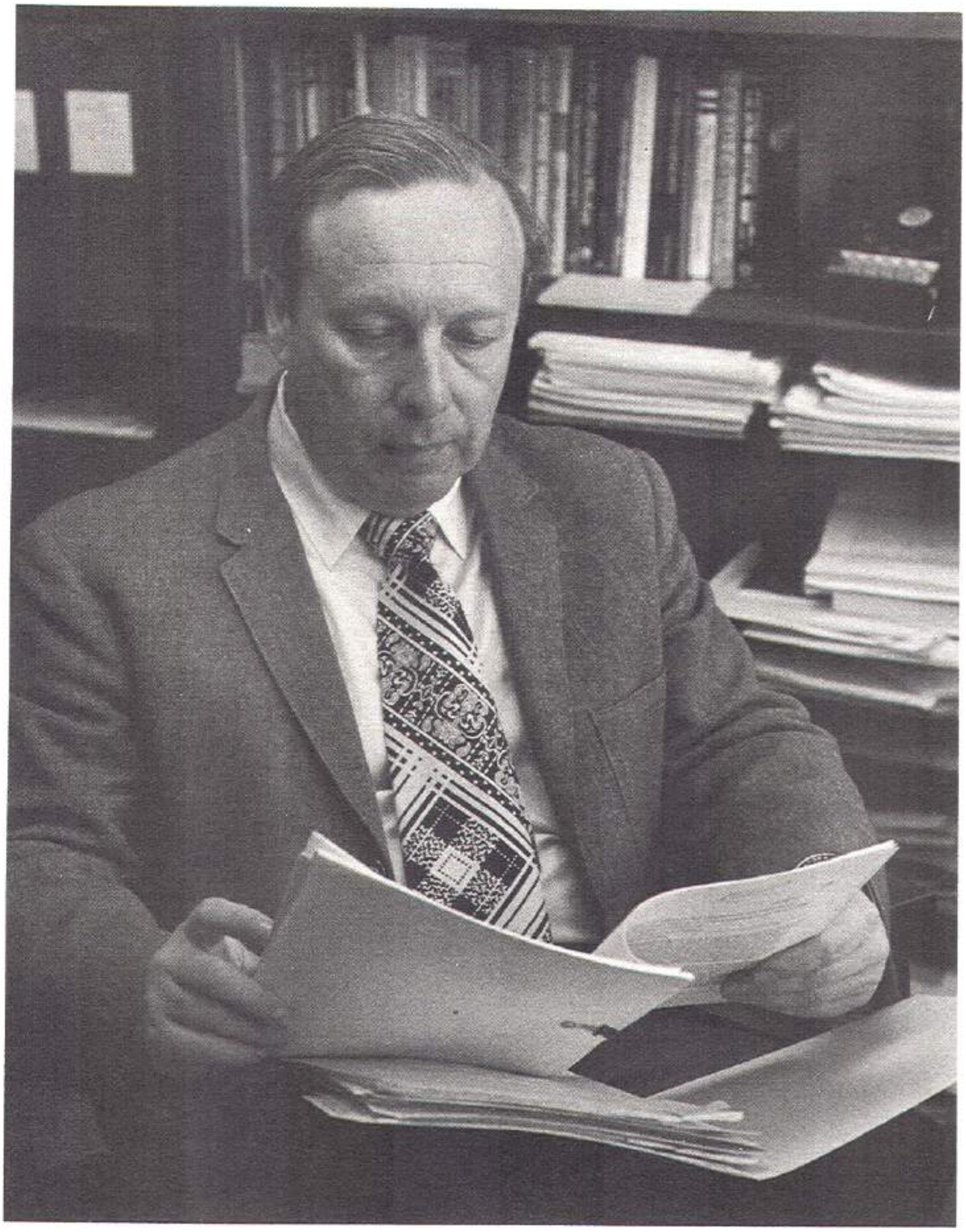
SHIRLEY HUGHES, R.N.

Shirley Hughes is a graduate of Queen's School of Nursing in her native state of Hawaii. She is the head nurse at the Dialysis Training Center where she coordinates patient care and scheduling and teaches a course in dialysis nursing care to the students in the Dialysis Instructors Training Program.



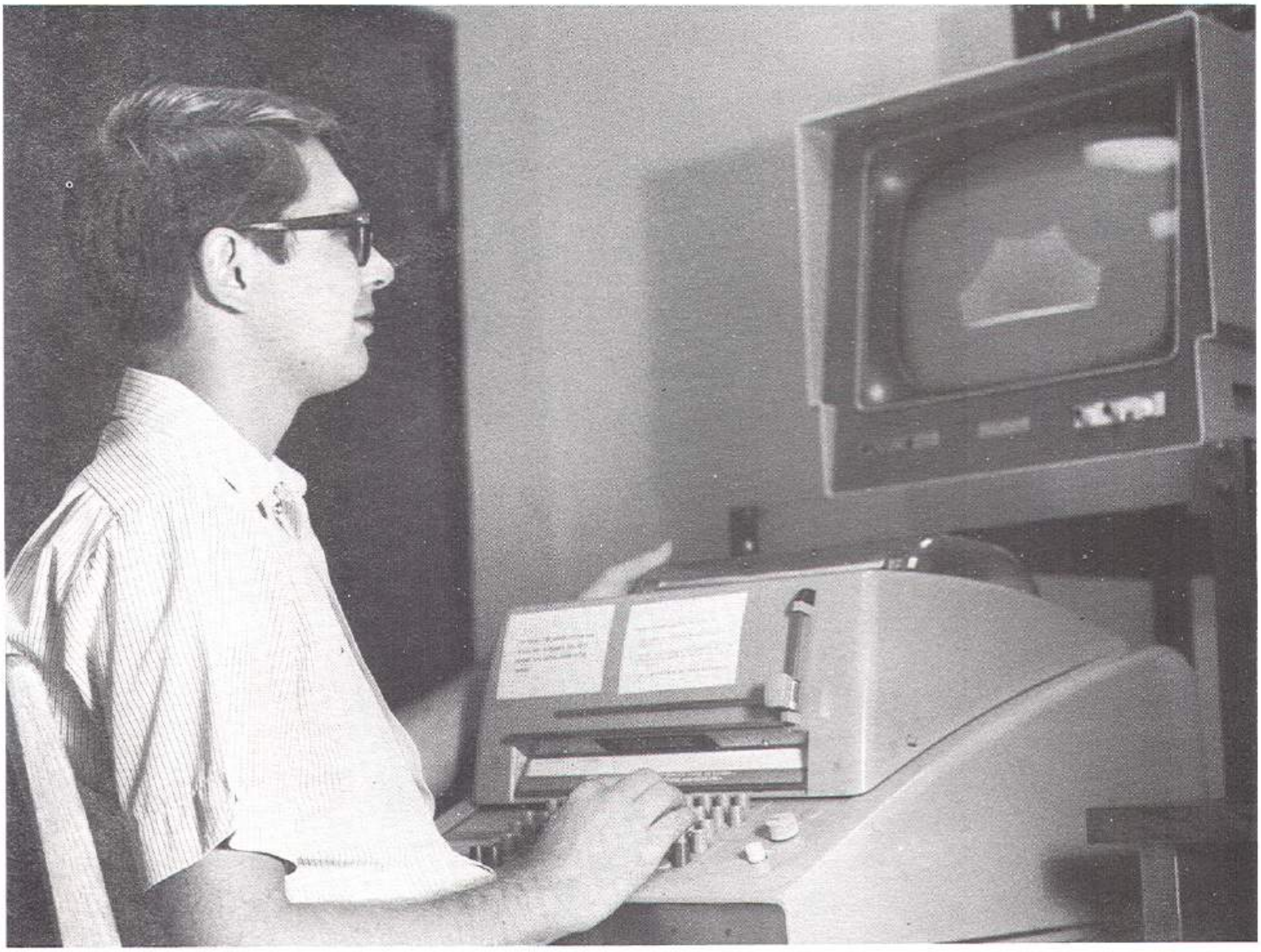
GERMAN RAMIREZ, M.D.

Dr. German Ramirez is an internist who was graduated from Universidad de Valle Medical School in his home town of Cali, Columbia in 1967. He served internships in both Cali and Boston, Massachusetts - the latter at Newton Wellesly Hospital. In 1971, he completed his residency in internal medicine at the Veterans Hospital, Brooklyn, New York, and came to the Dialysis Training Center at the University of Utah. In addition to patient care, Dr. Ramirez is working on a number of problems associated with chronic hemodialysis patients, such as the treatment of osteoporosis in which the artificial kidney removes calcium from the blood to such an extent that the body begins to mobilize the calcium in the patients' bones.



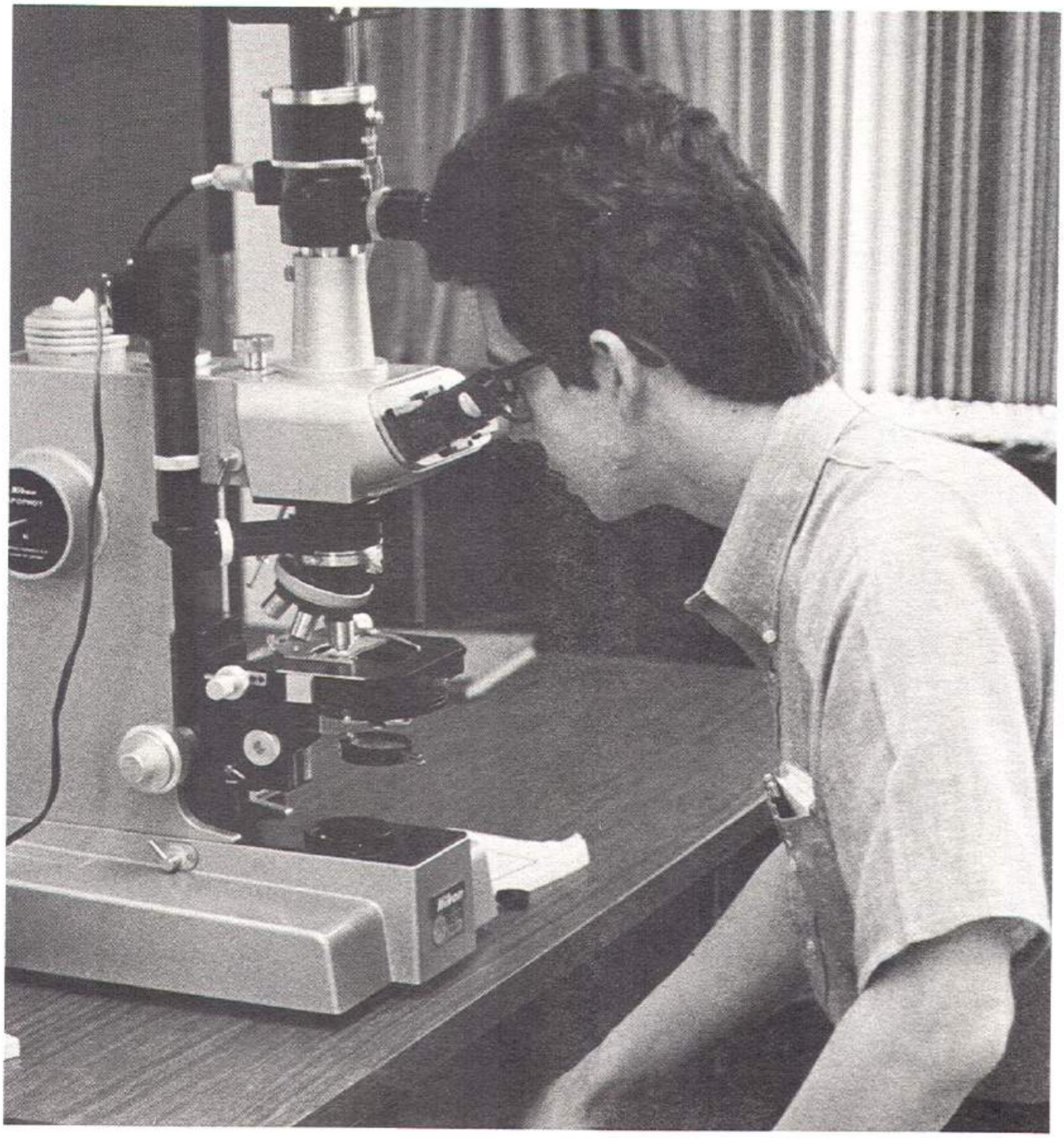
HARVEY GREENFIELD, Ph.D.

The University of Utah is widely recognized as a center for the development of Computer graphics, and Dr. Greenfield is the person responsible for introducing computer graphics as a tool in Medical research. Dr. Greenfield uses computer graphics to analyze the flow and stress patterns within the cardiovascular system. Of particular importance to our program is his analysis of flow and stress through various prosthetic heart valves. Since there is no entirely satisfactory valve as yet, Dr. Greenfield's work promises to be of great value in the improvement of such valves. Dr. Greenfield hopes to have the opportunity to expand his studies to include other areas of the circulatory system, such as the capillaries and the lung. Dr. Greenfield, whose Ph.D. is Physics was granted by Glasgow University, is much appreciated for his wit and his incisive questions during our planning meetings.



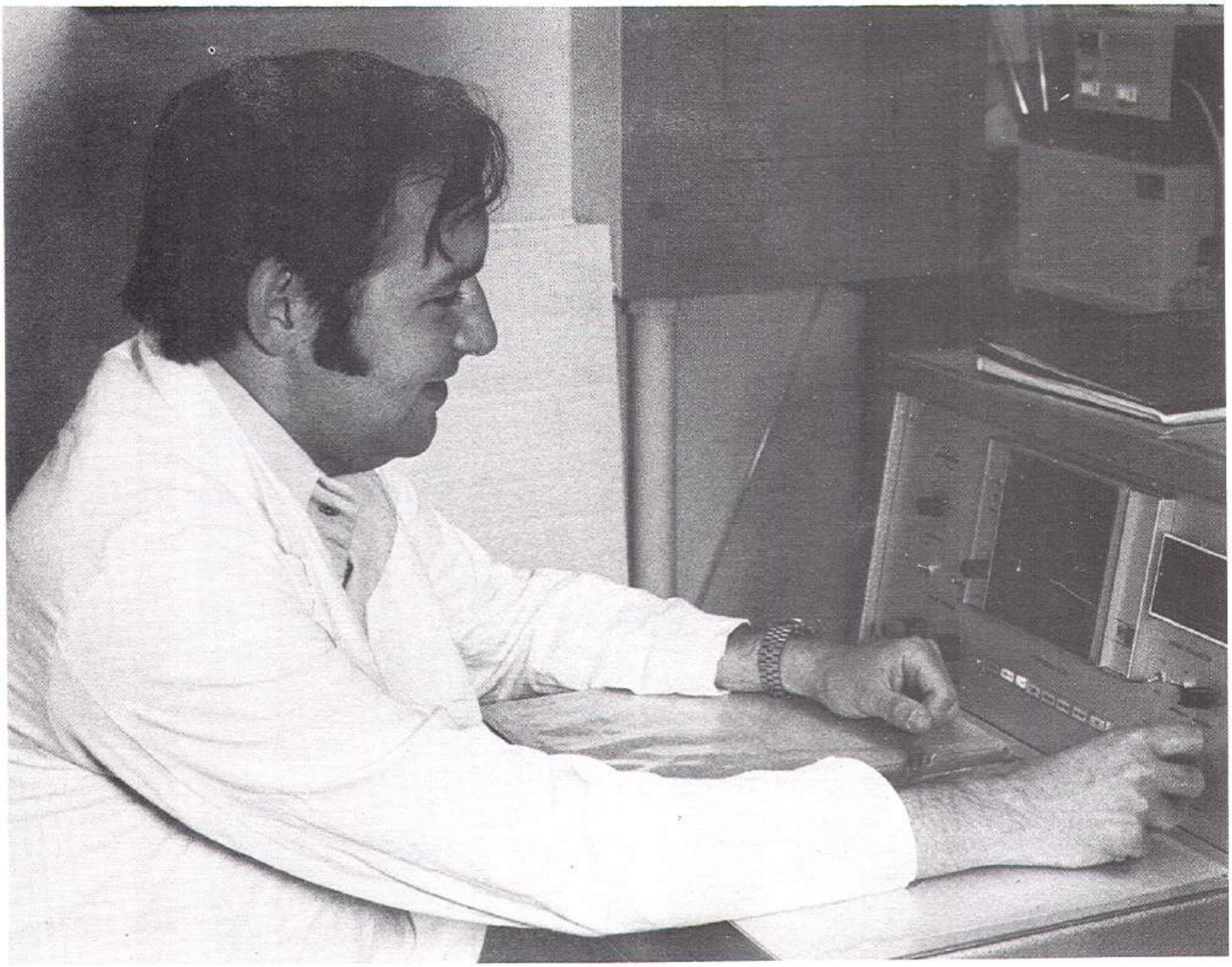
STEVE KELSEY, Ph.D.

Numerical analysis and computer graphics have recently become useful tools for the solution and visual simulation of medical phenomena to allow greater insight of the actual physical mechanisms involved. Dr. Kelsey is a Senior Research Associate in the Division of Computer Science working with Dr. Harvey Greenfield in analyzing the flow and stress patterns in the cardiovascular system. His doctoral dissertation in chemical engineering at the University of Utah entitled, "Isothermal and Nonisothermal, Newtonian and Non-Newtonian Entrance Region Flows" provided a basis for much of his present work. Solution of three-dimensional flow problems for non-Newtonian pulsatile flows with moving geometries and development of display methods for such problems hold Dr. Kelsey's present attention. In addition to playing the piano and organ, Dr. Kelsey is an avid genealogist.



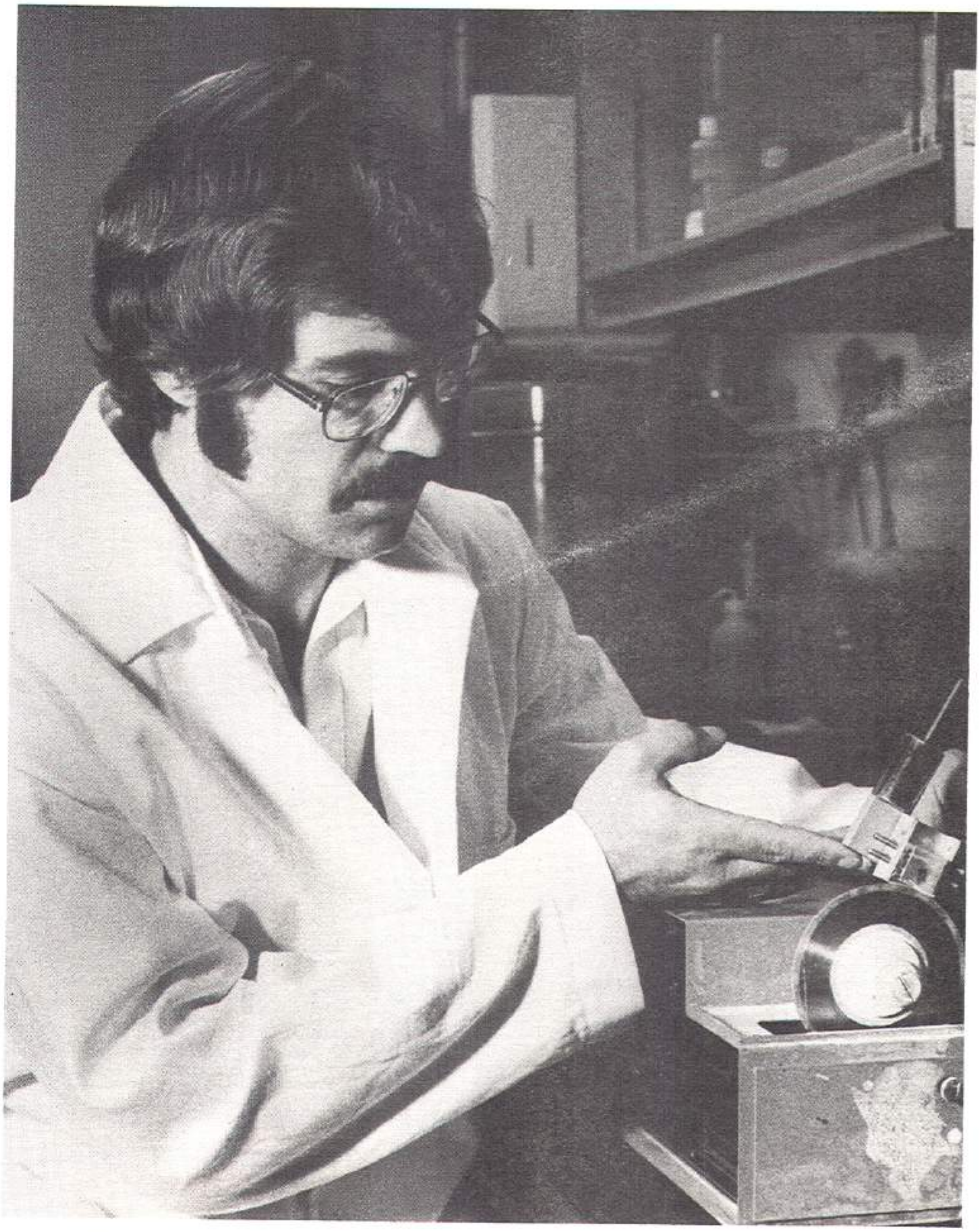
JOSEPH ANDRADE, Ph.D.

Dr. Andrade received his Ph.D. in Materials Science. He is in charge of a group whose task is to develop and test biocompatible materials. This work has led to promising results in several areas. An artificial flexor tendon for the hand and enzyme electrodes for the specific, continuous sensing of biochemicals are just two of these. Water and activated charcoal are two common materials with which Dr. Andrade is presently experimenting. The water is used to form synthetic hydrogels which can then be applied to the blood touching faces of artificial organs. Activated charcoal has been successfully used in an artificial kidney developed by Dr. Andrade.



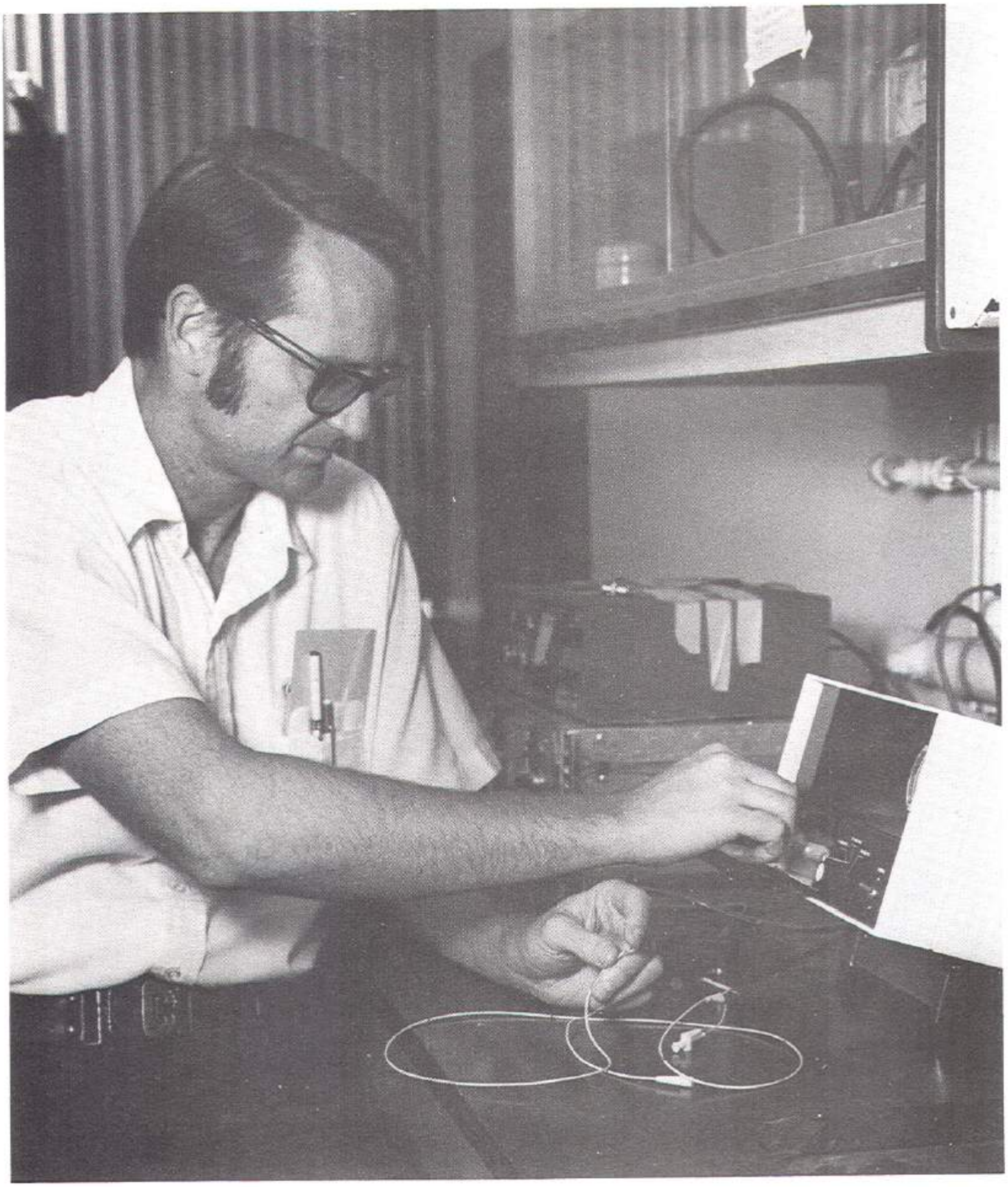
DAVID LENTZ, Ph.D.

Dr. David Lentz has degrees in both Organic and Physical Chemistry. He is working on surfaces for both the artificial heart and the artificial kidney. For the charcoal kidney, he is coating the granules of charcoal with hydrogels to increase its blood tolerability. He is also working on methods of grafting hydrogels to other materials for the artificial heart. These methods include using gamma radiation, ultraviolet radiation, and radio frequency plasma discharge. Dr. Lentz was formerly a teacher in his native New York. Since coming to Utah in 1969, he has acclimated himself by becoming a skier and gold miner in his spare time.



DENNIS COLEMAN, M.S.

Dennis Coleman works with Dr. Andrade's group, studying the biocompatibility of various materials, particularly the effect of blood and tissue on polymers with varying water content and the polymers' effect upon blood and tissue. His particular area of interest is in the "bio" portion of biomaterials. He has worked as a histopathology technician and is completing graduate work in pathology. He has also worked for some time as an experimental pathologist with the University of Utah Medical School Surgery Department.



CURTIS JOHNSON, Ph.D.

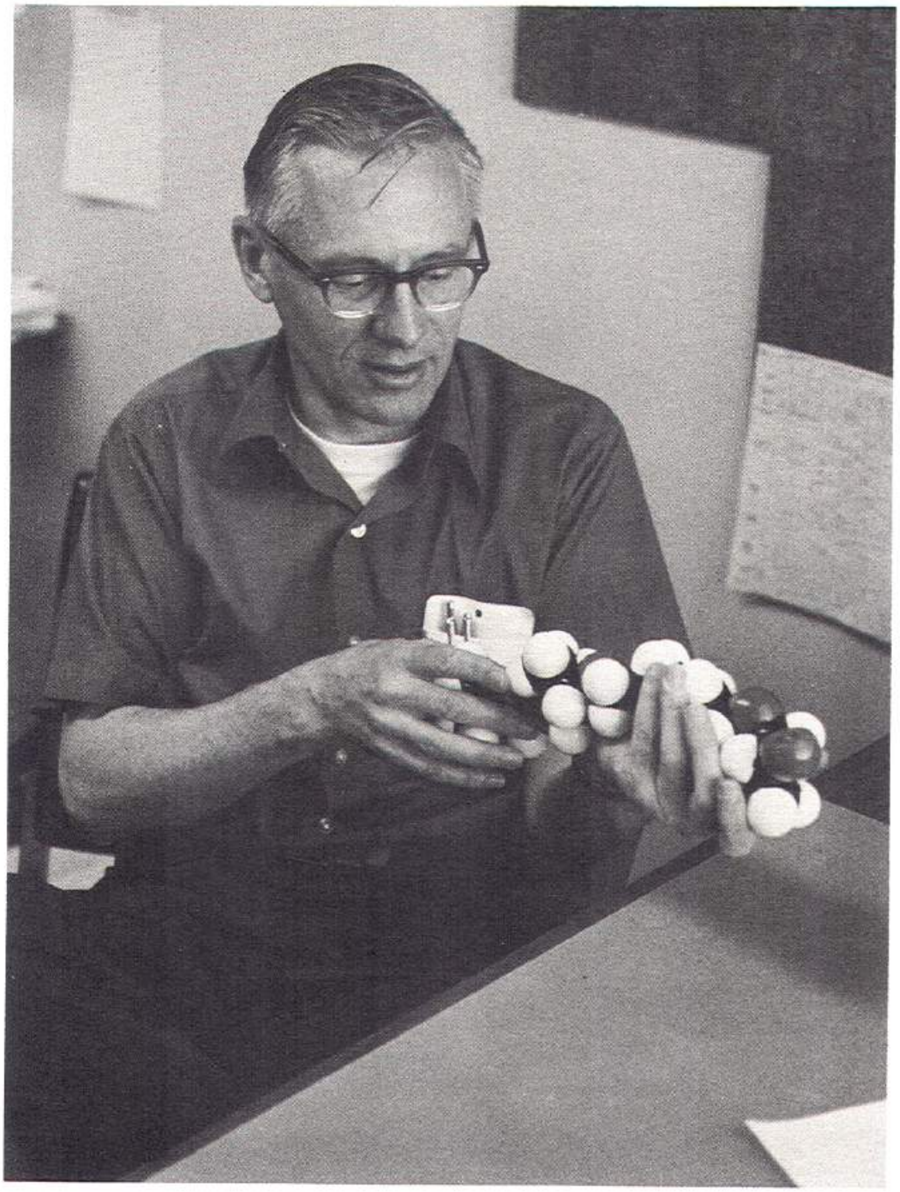
Dr. Curtis Johnson is an electrical engineer with degrees from California Institute of Technology and Stanford University. He is presently a professor in the Biophysics and Bioengineering Department, as well as Co-Director of the Institute for Biomedical Engineering. He has done extensive work in the field of bioinstrumentation. For example, he is perfecting a miniaturized solid state fiberoptic oximeter which will be capable of continuously measuring oxygen saturation within a patient's bloodstream. Dr. Johnson is also interested in ultrasonic devices which may be able to take the place of x-rays in many situations and also serve as monitoring devices.

STEVE JACOBSEN, Ph.D.

Dr. Jacobsen has returned to his Alma Mater, the University of Utah, after completing his Ph.D. in engineering at M.I.T., where his dissertation was concerned with control systems for a multiple axis artificial limb. This is a subject which continues to interest him. He is presently teaching courses on electromechanical systems and design while carrying on research in the area of rehabilitative engineering, principally in the design and control of prosthetic and orthotic devices. He has also contributed to the design of various blood pumping systems for the artificial kidney.

GARY SANDQUIST, Ph.D.

Dr. Sandquist is a native of Utah who completed most of his education at the University of Utah, except for a stint at the University of California at Berkeley, from which he received his M. S. He is currently Director of the Nuclear Engineering Program at the University of Utah. Dr. Sandquist believes that a miniature implantable atomic engine could serve as the power source for an artificial heart, and he is working on this project with several other members of our staff.

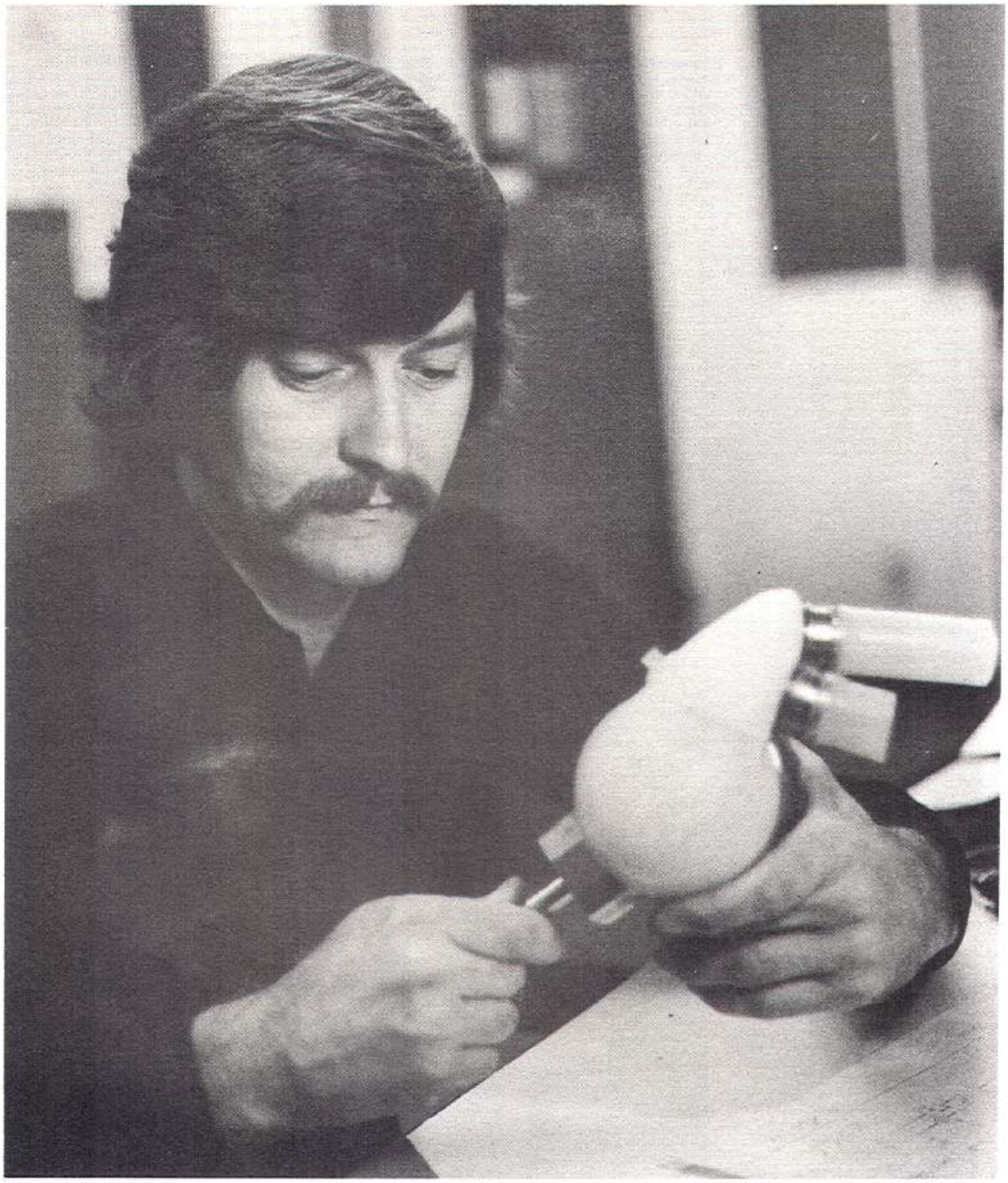


DONALD LYMAN, Ph.D.

Dr. Lyman is a polymer chemist who is currently Professor of Materials Science and Assistant Research Professor of Surgery. He was Senior Polymer Chemist at the Stanford Research Institute when he became associated with the efforts of researchers at the University of Washington School of Medicine to improve the artificial kidney. His interest in the complex problems of surface and diffusion reactions between blood and polymers grew, and in 1969, Dr. Lyman moved to the University of Utah in order to expand these studies which now include the production and resting of polymers used in artificial hearts, vascular grafts, extracorporeal treatment of blood, neurosurgery, orthopedic surgery and reconstruction surgery. Dr. Lyman is the author of fifty scientific papers and holds three patents. He is a prominent and active member of a number of chemical and biomedical organizations.

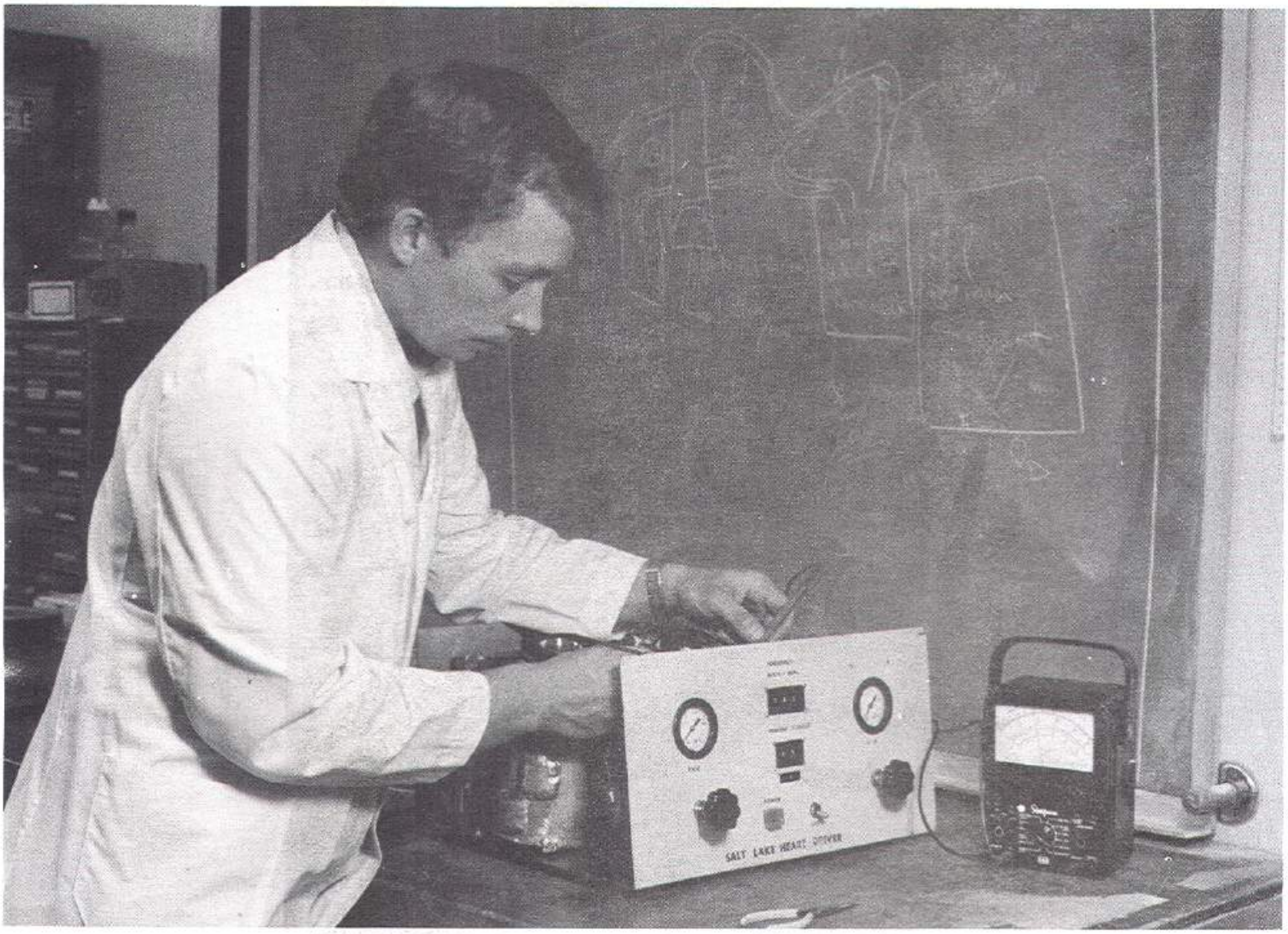
SUN WAN KIM, Ph.D.

One of the most vital problems facing researchers in the field of artificial organs is the question of exactly what happens when blood touches the surface of any artificial object. Dr. Kim is a biophysical chemist engaged in the study of just this phenomenon and has written more than two dozen papers largely concerned with such topics as protein adsorption, platelet interaction and membrane diffusion. Dr. Kim is an immigrant from Korea who has applied for United States citizenship.



KENT BACKMAN, Ph.D.

The Division of Artificial Organs includes surgeons, engineers of several types, chemists, physicists, veterinarians, physiologists, et al. so that we can combine the talents of a number of people for any one project. At the same time one man might be working on a variety of projects. Thus, Kent Backman, who has a Ph.D. in Mechanical Engineering, has worked on the artificial heart, the artificial kidney, the artificial eye and on other biomedical devices. For example, he helped to develop a bubble detector for the artificial kidney and a radio frequency telemetry system to measure strain on an implanted splint for the spine. His principal task at this time is to design an artificial heart which can be powered by a small implantable atomic engine which is in turn being developed by Westinghouse Corp..

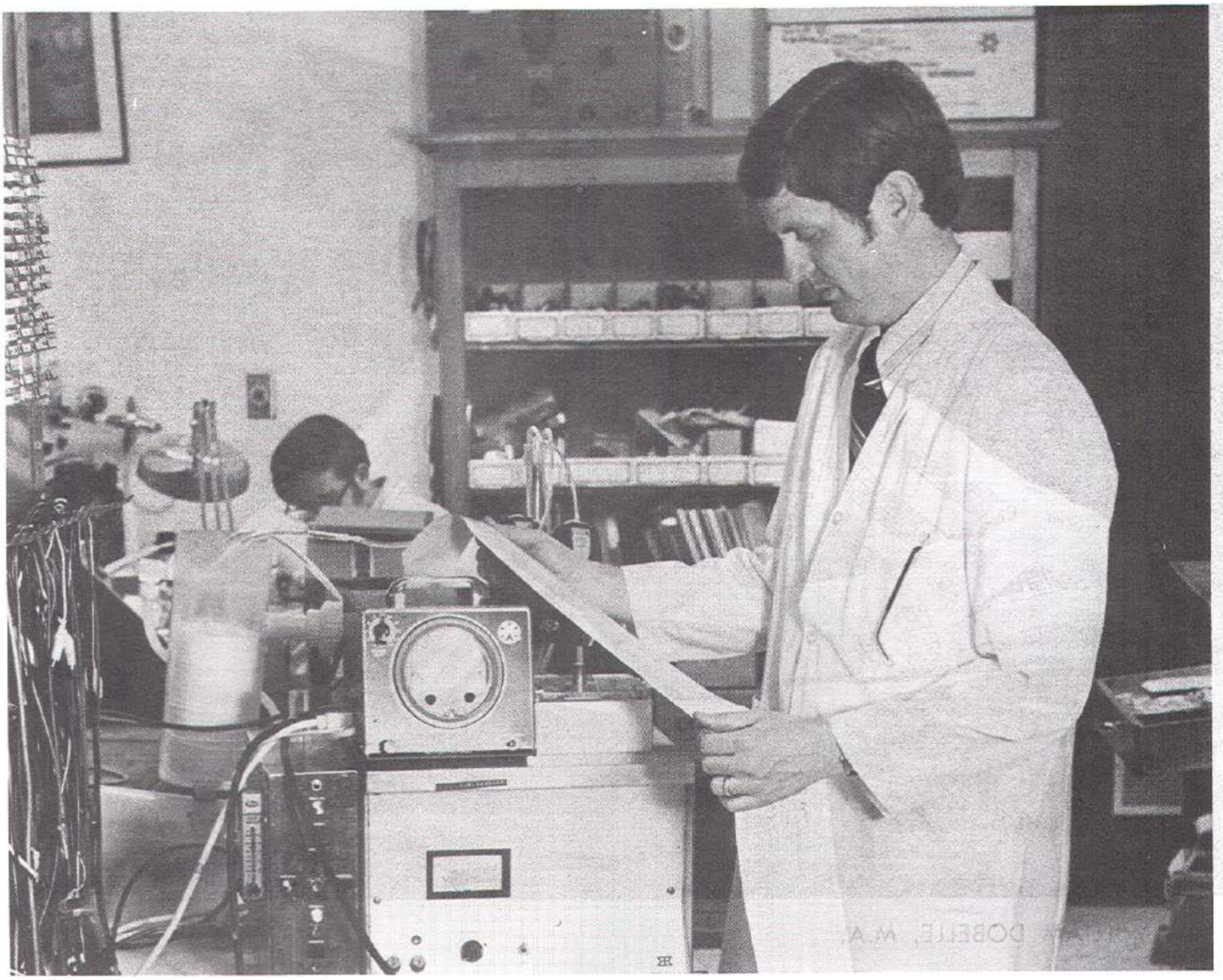


STEVE NIELSEN, B.S.

Steve Nielsen, an electrical engineer, is responsible for the design, construction and modifications of our heart driving svstem. Some of Steve's other areas of interest include motor controllers for a wearable artificial kidney, nonevasive monitoring of pressures and cardiac output of calves with artificial hearts, and automatic peritoneal lavage devices. He first became involved with the Division of Artificial Organs while he was a student in Electrical Engineering at the University of Utah. Upon graduation, Steve became a full-time member of our staff and finds this type of engineering fascinating.

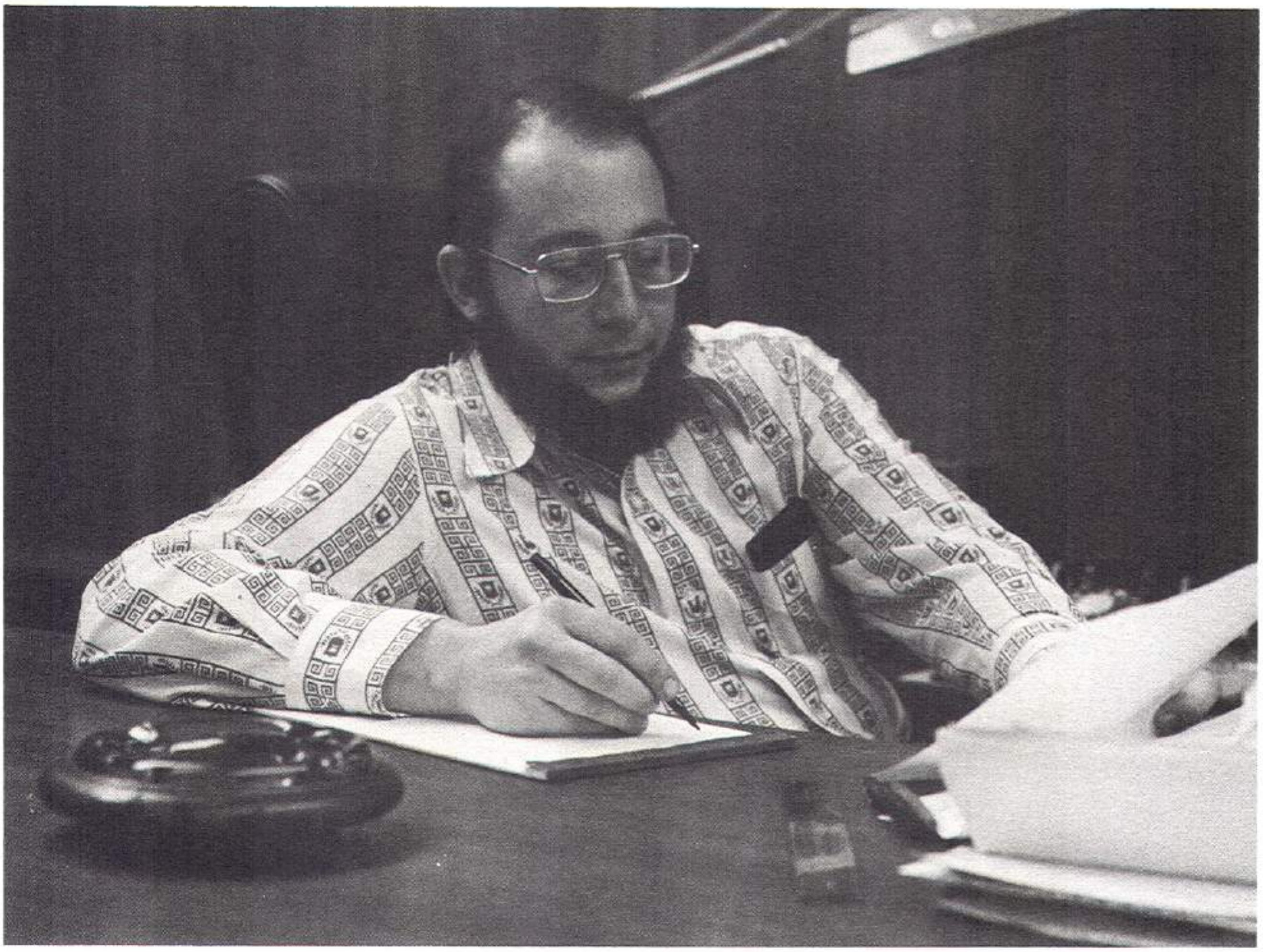
JERROLD FOOTE, B.S.

Mr. Foote is a physicist, a graduate of California State Polytechnic College, who has been involved with cardiovascular research for the past nine years. He designed a series of tests used for the evaluation of all artificial hearts in our laboratory. His particular area of interest is in the instrumentation of all kinds of artificial organs - the artificial eye and the artificial kidney, as well as the artificial heart. At the present time, he is working on a method for determining circulatory blood pressures of animals with artificial hearts without the use of catheters. This is of great importance because catheters often cause the formation of blood clots and they serve as easy routes for infection to enter the animals. Mr. Foote shares with several members of our staff an interest in home made aircraft and rebuilding classic automobiles.



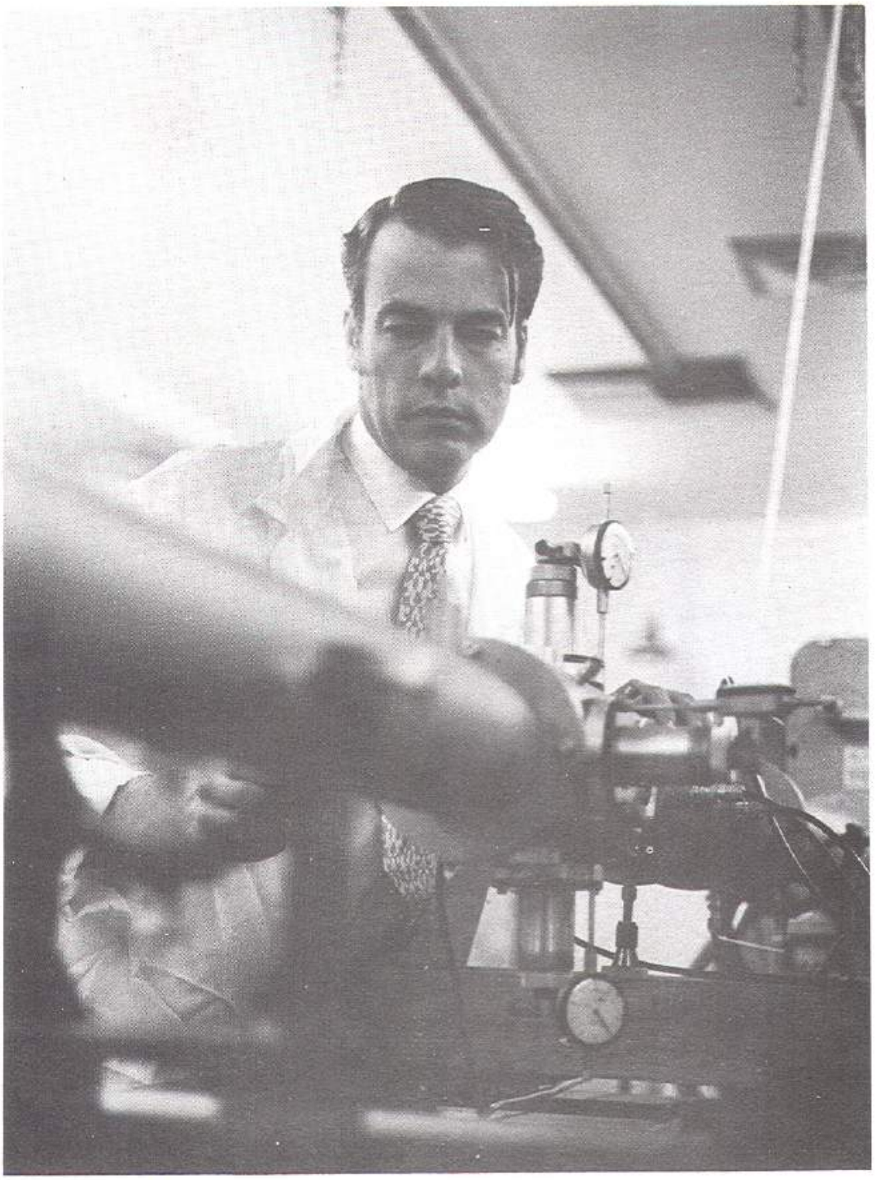
ROGER KIRKHAM, M.E.A.

Roger Kirkham completed his Master's Degree in Industrial Engineering, while working on the development of less expensive and more efficient artificial kidneys. This is a project with which he is still involved. He is convinced that a wearable artificial kidney should be the next goal of research in this area - a goal which he believes will soon be realized. For the past two years, Mr. Kirkham has coordinated all of the engineering activities of the Division of Artificial Organs, and he is quite interested in problems of management. The financing of home dialysis has undergone a rapid transformation in the last few years - a development which Mr. Kirkham believes creates a need for imaginative management.



WILLIAM DOBELLE, M.A.

Mr. William H. Dobelle is the project manager for the artificial eye project. Although he is a young man, Mr. Dobelle has had extensive experience, both in the scientific study of the eye and in administration. Immediately after completing his B. A. at Johns Hopkins University, he became executive director of the Medical Eye Bank of Maryland, Inc. and saw that organization through a period of rapid growth and development. At the same time, he served as president of Specimens Unlimited, a company specializing in the collection of exotic scientific specimens. During this period he also completed his M.A. in Biophysics at Johns Hopkins. Temporarily abandoning science, Mr. Dobelle became the executive director for the Republican State Central Committee for Maryland in the election year of 1968. He has been with the Division of Artificial Organs since 1969 and continued his energetic activity by also completing most of the requirements for a Ph.D. in Physiology at the University of Utah.

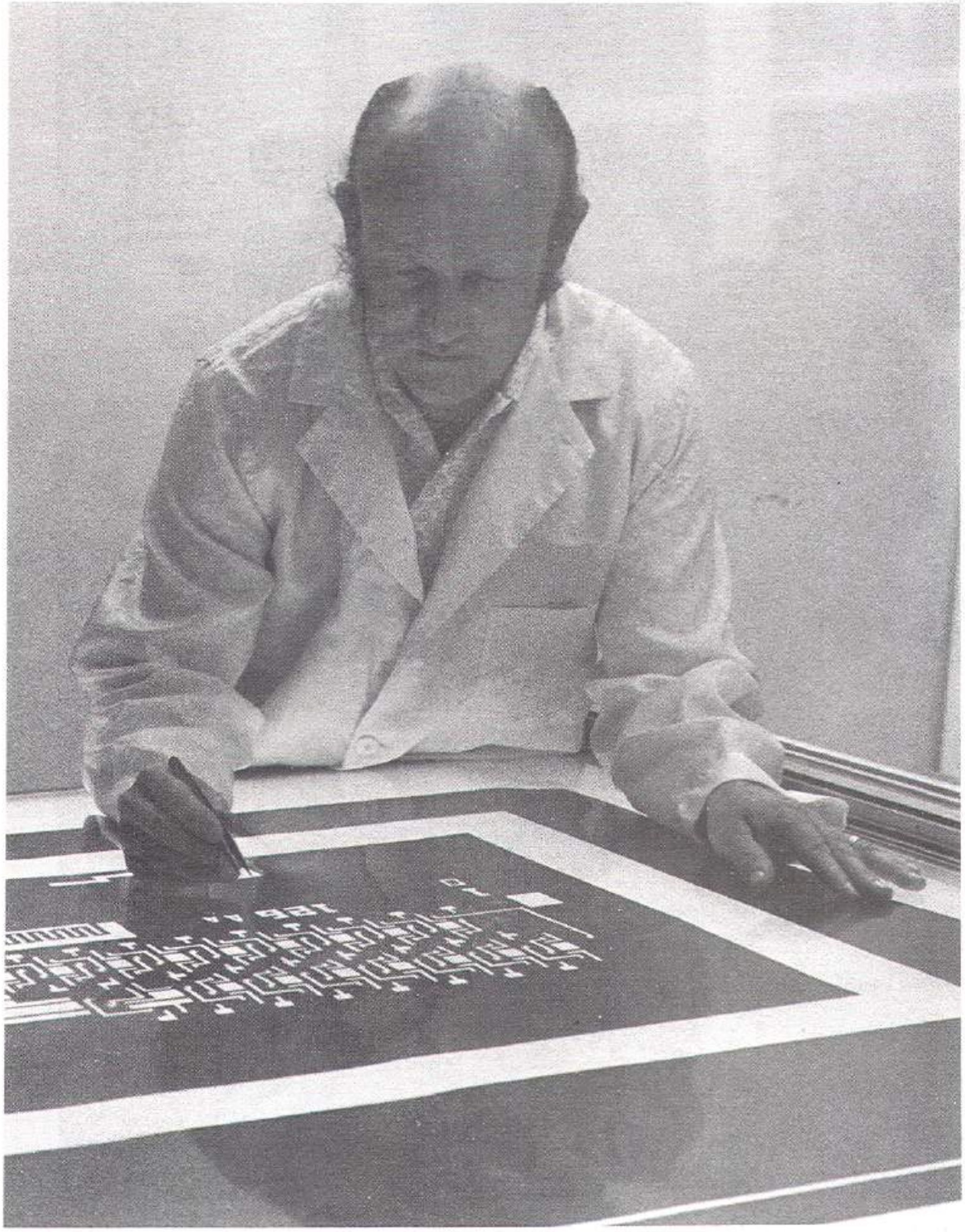


ROBERT HUBER, Ph.D.

Robert J. Huber, Ph.D. is presently Director of the Microcircuit Lab of the Institute for Biomedical Engineering at the University of Utah. He joined the University of Utah in July 1971, specifically to establish such a laboratory. Due to the generosity of a number of industrial firms, the University now has extensive capability in the field. From 1967 to 1971, he was associated with the General Instrument Corporation Microelectronics Research Development Center as physicist, associate director and director. Integrated circuit processes he helped develop now form the basis of much of the commercial integrated circuits sold by the General Instrument Microelectronics Division. He previously had six years' experience in the field of nuclear reactor physics and semiconductor radiation detector studies - the latter subject leading directly into the field of semiconductor electronics. Dr. Huber also has had considerable teaching experience, both during his current academic appointment and previously in academic programs sponsored by the University of Idaho beginning in 1961 and later by the University of Utah.

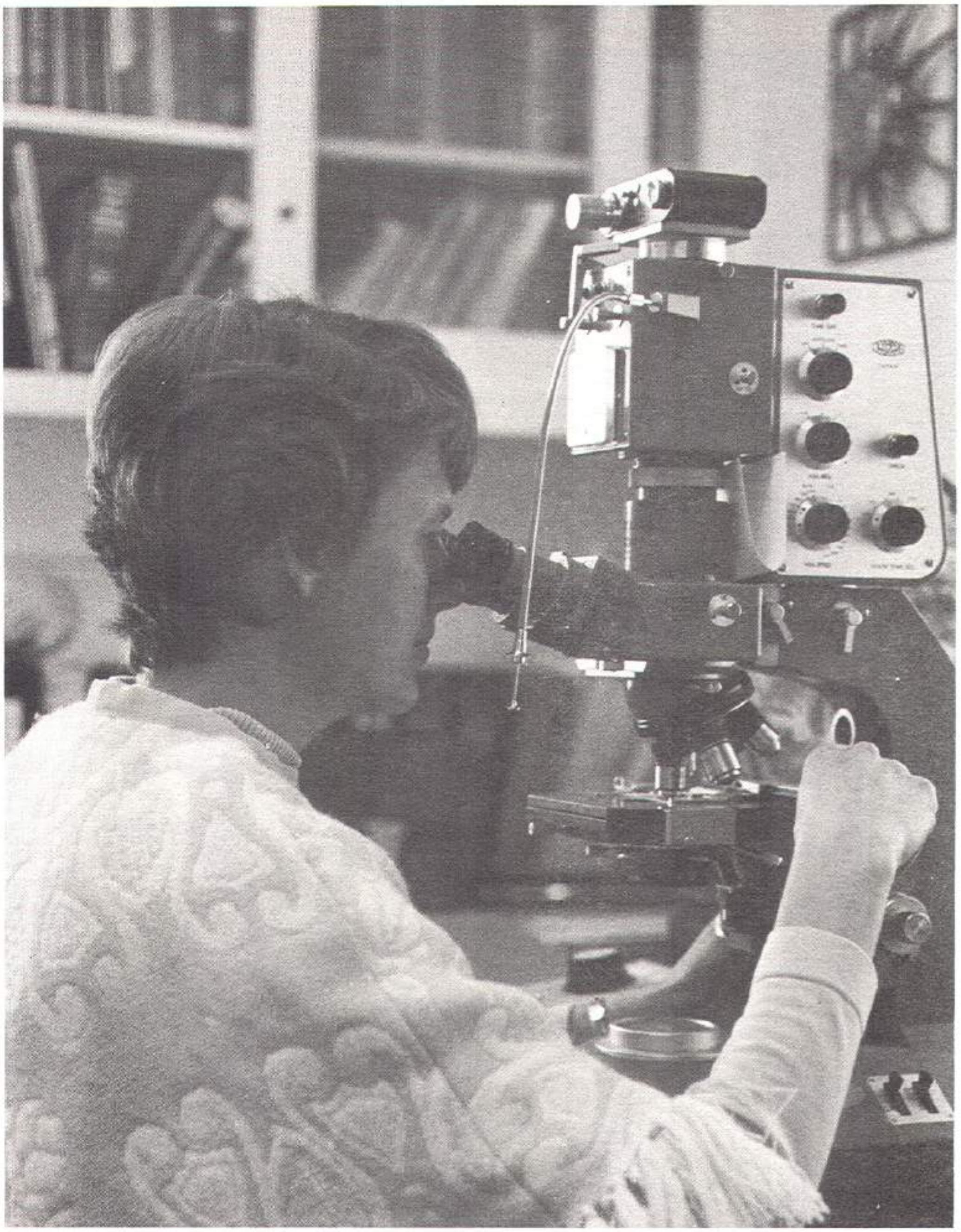
MIKE MLADEJOVSKY, B.S.E.E.

Michael Mladejovsky came to the United States from Czechoslovakia by way of Australia. He is completing requirements for a Ph.D. in Electrical Engineering and Computer Science at the University of Utah. He is responsible for instrumentation used in the human brain stimulation experiments for the artificial eye. For this purpose, he developed a computer driven 64 channel stimulator. His particular area of expertise is the combining of microelectronics devices with computer operation.



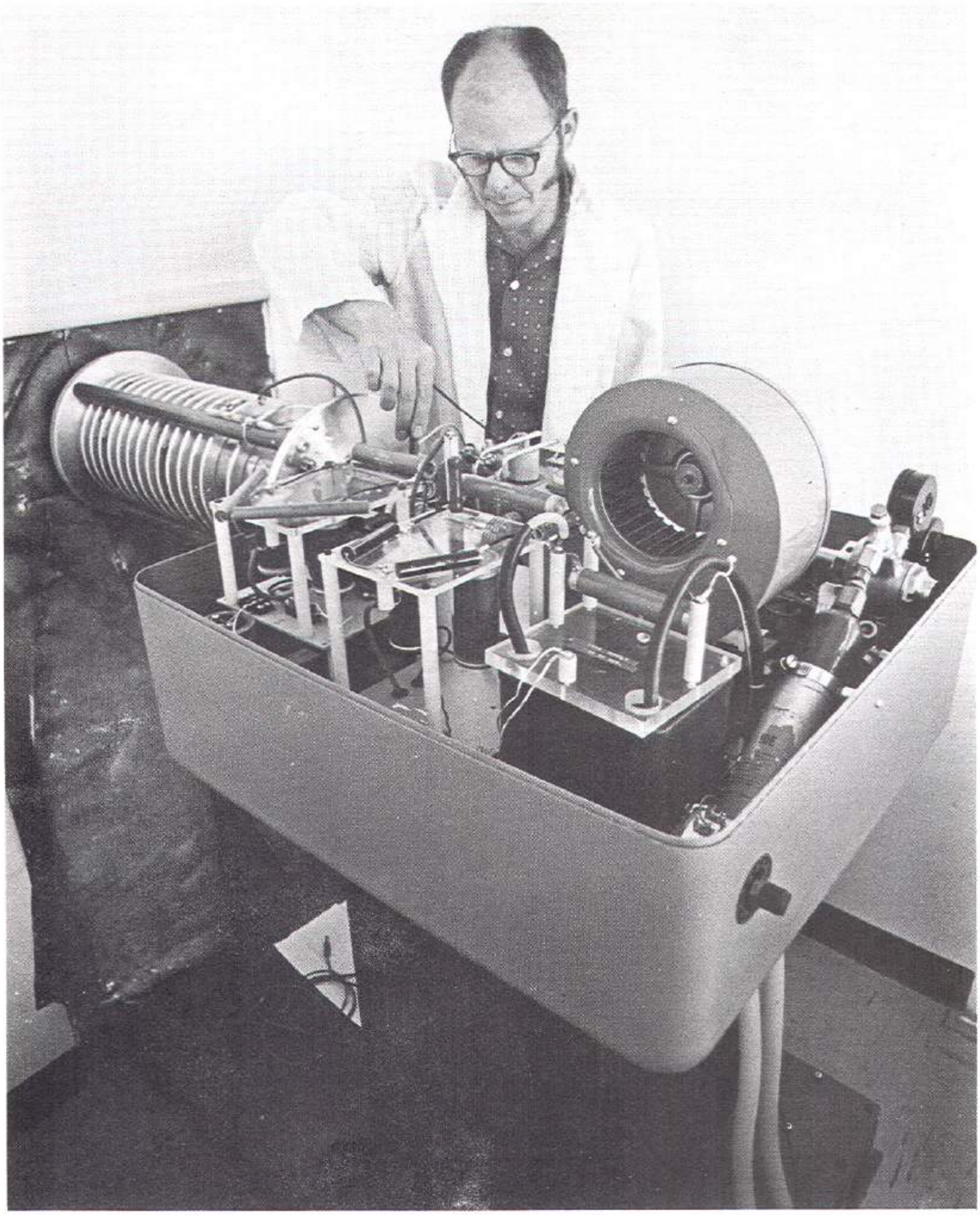
DON HILL, B.S.E.E.

Mr. Don Hill is a microcircuit design engineer with the Microcircuit Lab. He was graduated from Oregon State University, and has been engaged in a variety of electronic system designs since that time. While working for IBM, he began development work on microcircuits for aerospace data systems and has been working for the past seven years in this field. He is currently working on the design and development of microcircuits for biomedical applications, such as microminiature computers, multiplexers and other such devices. He has recently completed a design for an integrated circuit "read only memory" for miniature computer applications. This circuit contains approximately 8000 MOS transistors on a single silicon chip and is now fully operational.



SUZANNE STENSAAS, M.A.

Mrs. Suzanne Stensaas is a neuroanatomist who has done work on the development of the cerebral cortex and the morphology of glial cells. In 1970 she was appointed to the Faculty of Medicine at the University of Utah where she teaches neuroanatomy and works with the Division of Artificial Organs on the artificial eye project. She is currently studying the compatability of biomaterials with the central nervous system and the effects of electrical stimulation on the brain using techniques of light and electron microscopy. She has recently enrolled in the University's Ph.D. Program in Anatomy. With whatever time she has left from her teaching, her research, her studies and taking care of her husband and child, she indulges in the nearly universal Utah pastimes of skiing, hiking and camping.

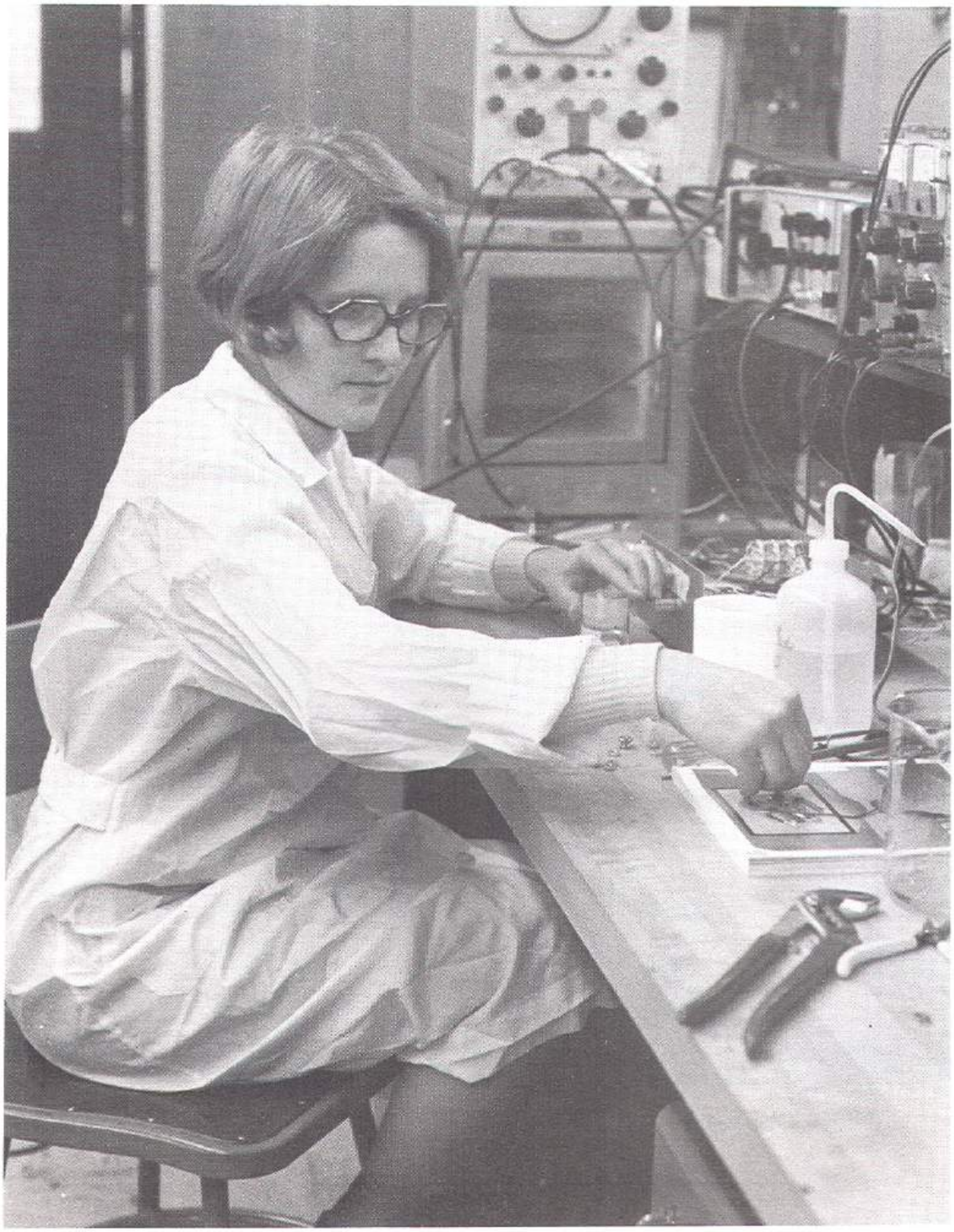


JIM FORDEMWALT, Ph.D.

Dr. James N. Fordemwalt, who was graduated with a Ph.D. in Physical Chemistry from the State University of Iowa, is well known for his book on integrated circuits, which is the standard reference work for the electronics industry. He has spent a number of years working for major firms in the industry, such as General Electric, Motorola and Philco-Ford. While he was Assoc. Director for Research and Development for American Microsystems, Inc., he became involved with the artificial eye project, which interest eventually brought him to the University of Utah. He is also working on the artificial ear.

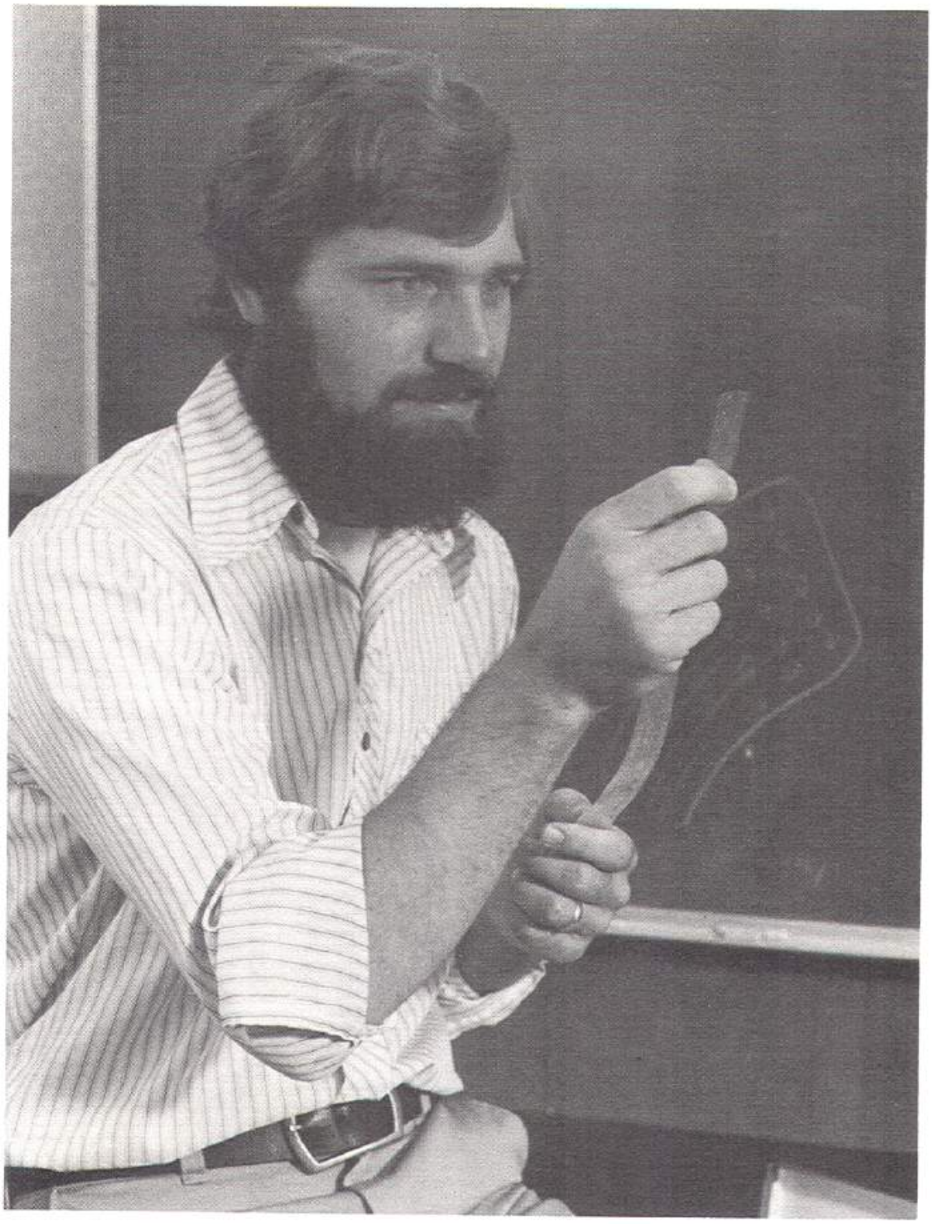
JOHN HANSON, Ph.D.

Dr. John W. Hanson's formal education was in electrical engineering and physics. He has recently taken graduate courses in medical physiology. He has worked for several firms involved with the evaluation of electronic systems for the space program. He is an expert on ion-implantation technology for the production of integrated circuits. This is a new technology which has made it possible to manufacture smaller, faster and lower powered circuits than heretofore possible by any other means. His current interests are the design and processing of integrated circuits for application to research in medicine and physiology as for example, in the artificial eye and artificial ear.



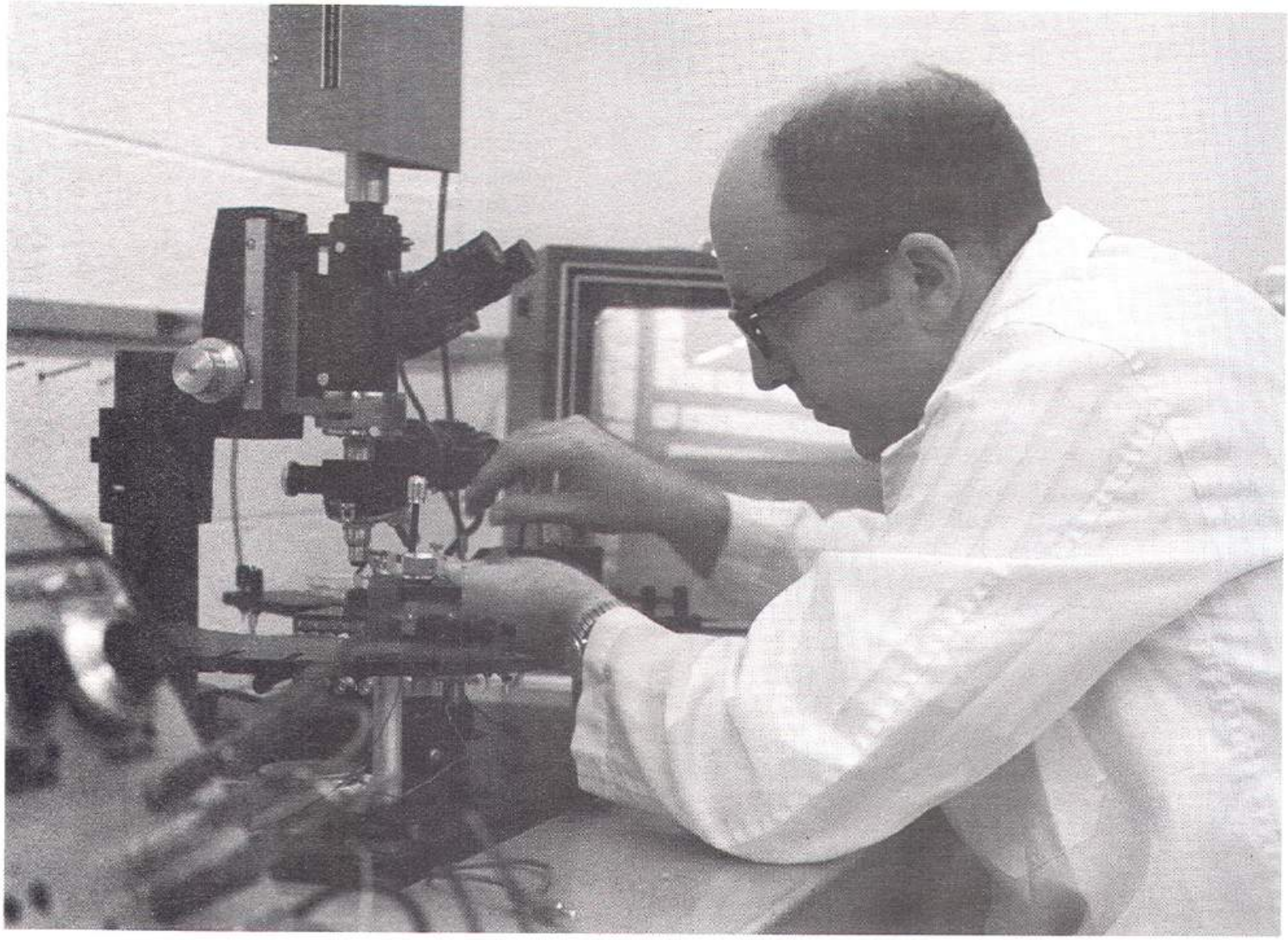
JEAN SMITH, Ph.D.

Dr. Jean Smith received her Ph.D. in analytical chemistry from the Univ. of Kansas. She has taught chemistry at several universities and colleges including the University of Utah. She is now working on the artificial eye project. The artificial eye is intended to bypass the optic nerve and to directly stimulate the brain with electrical energy. Dr. Smith is analyzing the chemical changes that occur in the cerebral spinal fluid when electrical current is passed through it. The results of her studies will help to determine the parameters within which the stimulation can be attempted.



GREG DULMAGE

Improvement of the artificial eye is dependent upon experiments in which our scientists stimulate the sight control centers of the brain of volunteers. The volunteers are all people who, for some reason, must undergo brain surgery. Since such volunteers are not very common, our scientists working on the artificial eye often travel to various cities in the United States and Canada. Greg Dulmage goes before our experimental group to spend time with our patient-volunteers to tell them what the experiment is and how it will affect them. He stays with the volunteers during and after surgery. He is uniquely qualified for this work, both through his academic training as a psychology student at the University of Utah, and especially because he was the third volunteer in our series of experiments. He underwent surgery to correct an A-V malformation which was the result of a football injury and volunteered for electrical stimulation in the neural-prosthesis project. He has been briefing and interviewing all volunteers since 1971.



KENT SMITH, M.S.

Mr. Kent Smith is an electrical engineer who has had extensive experiences in the design of integrated circuits. He has designed many that are currently standard products of the electronics industry. He has also designed and developed the first computer controlled testing device for MOS circuits. He wrote the first MOS design manual. He is presently engaged in the design of circuits for the artificial eye. He also hopes to be able to develop some ideas that he has for heart pacemaker circuits.

SCIENTIFIC PERSONNEL

**Jospeh Andrade, Ph.D.	Materials Scientist
Kent Backman, Ph.D.	Mechanical Engineer
Dennis Coleman, M.S.	Experimental Pathologist
William Dobelle, M.A.	Biophysicist
Greg Dulmage	Research Assistant
Neil Eastwood	Operating Room Supervisor
Jerrold Foote, B.S.	Physicist
Jim Fordemwalt, Ph.D.	Electrical Engineer
Harvey Greenfield, Ph.D.	Physicist - Computer Scientist
Steve Greenhalgh, B.S.	Research Assistant
Erkki Haapanen, M.D.	Nephrologist
**Edwin Hershgold, M.D.	Hematologist
Don Hill, B.S.E.E.	Electrical Engineer
*Douglas Hill, Ph.D.	Microbiologist
Robert Huber, Ph.D.	Physicist
John Hanson, Ph.D.	Electrical Engineer
Shirley Hughes, R.N.	Head Nurse, Dialysis Center
Nobutoshi Imaizumi, M.D.	Immunologist and Surgeon
**Steve Jacobsen, Ph.D.	Mechanical Engineer
Robert Jarvik, M.S.	Research Assistant
**Curtis Johnson, Ph.D.	Biophysical Engineer
Mary Johnson	Executive Secretary
**Steve Johnson, B.S.	Artist - Photographer
Steve Kelsey, Ph.D.	Chemical Engineer
Tom Kessler	Plastics Technician
**Sun Wan Kim, Ph.D.	Chemist
Roger Kirkham, M.E.A.	Project Engineer
W. J. Kolff, M.D., Ph.D.	Internist
**Clifford Kwan-Gett, M.D.	Surgeon
John Lawson, Ph.D.	Postoperative Care
David Lentz, Ph.D.	Physical Chemist
**Donald Lyman, Ph.D.	Polymer Chemist
Peg Miller, M.A.	Social Worker
Mike Mladejovsky, B.S.E.E.	Electrical Engineer
Mike Nielsen, B.A.	Research Assistant
Steve Nielsen, B.S.E.E.	Electrical Engineer
Don Olsen, D.V.M.	Veterinarian
Hartmut Oster, M.D., Ph.D.	Surgeon
Jeffrey Peters, Ph.D.	Physiologist
German Ramirez, M.D.	Nephrologist
Lowana Reese	O.R. Scrub Nurse
Walter Rohloff	Machinist
**Gary Sandquist, Ph.D.	Mechanical Engineer (Nuclear)
**Jean Smith, Ph.D.	Electrochemist
Kent Smith, M.S.	Electrical Engineer
Lee Smith, M.S.	Materials Engineer
**Ted Stanley, M.D.	Anesthesiologist
Suzanne Stensaas, M.A.	Neuroanatomist
Elisabet Thor, M.D.	Internist
Dietz van Dura	Chief Dialysis Technician
Jay Volder, M.D.	Cardiac Surgeon
John Warner, B.S.	Administrator

* Consultants
** Part-time