People and medical technology

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PEOPLE AND MEDICAL TECHNOLOGY

Afscheidscollege

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Afscheidscollege

A farewell-address on
March 24, 1995.
Eindhoven University of
Technology

Prof.dr.ir. J.E.W. Beneken

Honorable Rector Magnificus,
Ladies and gentlemen,

Introduction

The reason I chose the title: "PEOPLE AND MEDICAL TECHNOLOGY" is twofold:

1. *To recognize different people who have been so important to me in my development and who offered me so many opportunities.*

2. *To emphasize that in science and technology, as in practically all corners of human society, people and their relations (called "networks", these days) are of primary importance.*

Networks are particularly important in multidisciplinary activities, more than in many other fields of science and technology. It takes special dedication to understand and communicate with people in a DIFFERENT discipline. Multidisciplinarity is more than just two or more disciplines together.

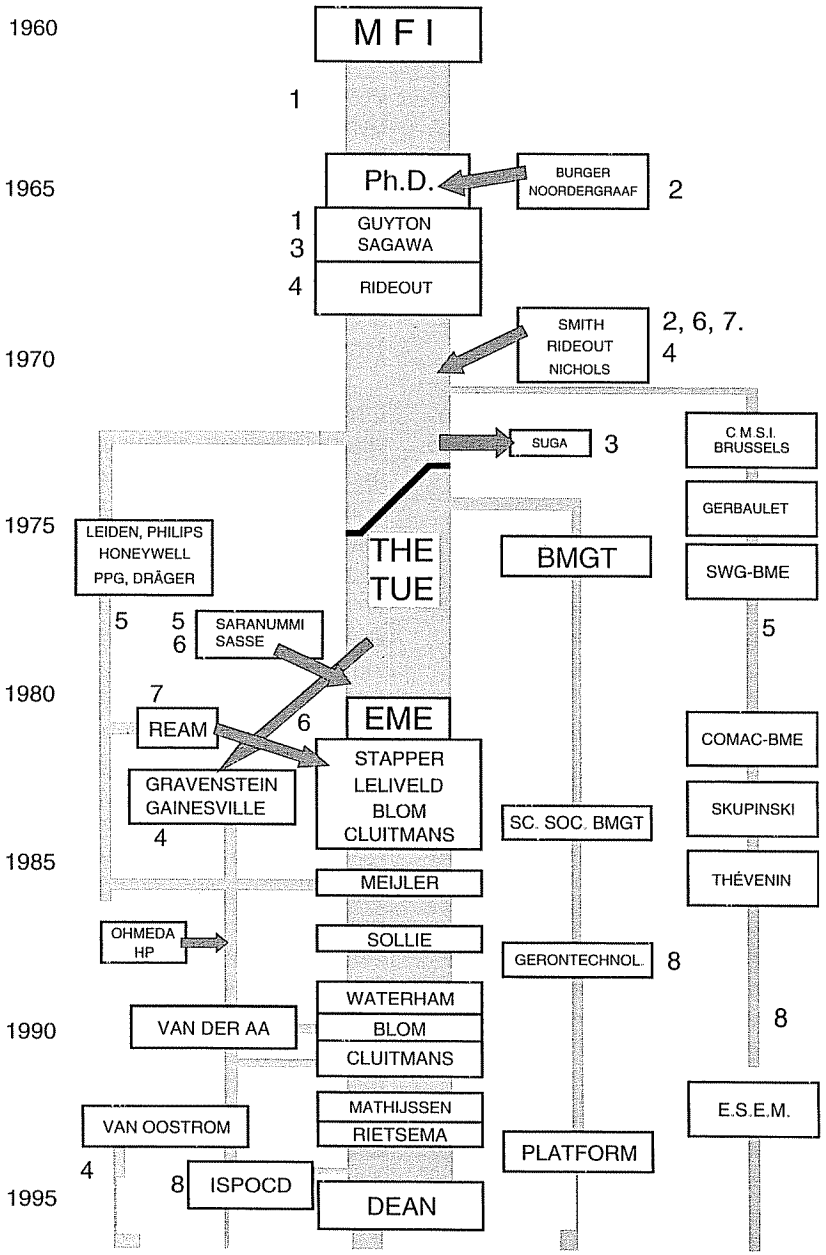
I plan to spend some time showing you where some of my research results have taken me. Subsequently, I will volunteer some opinions about relations with industry and health care and the consequence this will have for some of my activities in the near future.

In order to be able to show the links between past and present, and between different parallel activities, I have made a time diagram and the numbers therein will be referred to in the text.

How it started

It is always interesting to remember who or what set you on your way. In my case it was the Delft student body (ETV) of the EE department that organized an exhibition on Electrical Engineering and Health Care around 1956; and this exhibition sparked my interest. I started to inquire about graduation projects in this field and talked to Prof.ir. M. Breedveld, professor in electronics. Prof. Breedveld contacted Ir. D.H. Bekkering for me, who was the director of the TNO Institute of Medical Physics (MFI). As a key component of an analog simulator for the human blood circulation, Bekkering needed a logarithmic/anti-logarithmic amplifier to perform mathematical calculations. The sliderule was our most trusted companion in those days! This project was successful and the results were presented at a conference in Strassbourg.

ACTIVITY AND RELATION DIAGRAM



How it continued

I was enticed by the stimulating and amiable atmosphere at the institute and by the prospect of working on the simulation the human blood circulation together with Bekkering. In 1960, I started to work, assisted by one very dedicated technician. In the following years we created the largest analog computer in the Netherlands for our circulation model: partly bought, partly built. The model contained a precise representation of the heart and the heart muscle and a thorough analysis of the blood circulation as a closed system, with two pumps (the chambers of the heart) connected by elastic and collapsible tubes.
In 1963, during the International Physiology Congress in Leiden, I approached the great Dr. A.C. Guyton who had given presentations about the application of principles of physics to the circulation and who had followed this up by animal experiments. He must have thought that this young engineer, who had never seen a heart or a blood vessel in real life, was missing something very important and was running the risk of continuing to work at a very abstract level of physiology.
Dr. Guyton invited me to come to Jackson, Miss. for a fellowship after I had finished my Ph.D. (Figure 1, (1)[1]).
This Ph.D. was completed in 1965 under the excellent guidance of Prof. dr. H.C. Burger and of Dr. A. Noordergraaf (2), who then was commuting back and forth between Utrecht and Philadelphia.
Later the model was extended to represent the most essential control mechanisms to simulate the cardiovascular behavior under shock conditions.

U.S.A.

During my subsequent stay in Jackson Miss. in 1966 and 1967, as a United States Public Health Service post-doctoral fellow, (1) I worked intensely in the "wet" physiology with Dr. Arthur Guyton and Dr. Kiichi Sagawa (3) on coronary circulation and heart function. We became close friends to both families. I had the opportunity to discuss extensively the work I had done in my thesis on the heart and heart muscle with Ed Sonnenblick from NIH, who later went to Boston, and with Lloyd Hefner from Birmingham AL. The overall heart function curves were later confirmed by Sagawa and Suga and formed the basis for their simplified representation of the ventricular function (3). This simplification, incidentally, deserves to be referred back to Dr Homer Warner from the LDS Hospital in Salt Lake City who published this concept in 1963.

[1] *This and subsequent numbers refer to the equivalent numbers in the activity and relation diagram.*

Following Mississippi, the family moved to Madison Wisc. in September 1967 where I worked for one semester as visiting associate professor in close cooperation with Prof. Vince Rideout. We held extensive discussions as to whether we would ever be able to identify all relevant parameters related to the blood circulation from the few available measurements; yet "doctors" apparently acquired sufficient information for the treatment of the patient from the same limited number of measurements!
The real and lasting result (apart from good friendship) was our joint IEEE publication on multiple modelling, describing how transport of gases and other substances could best be simulated. This is the basis for much of the later work I was involved in (4).

In the late sixties, Dr. Noordergraaf (2), whom I mentioned in relation with my Ph.D., told me at a conference that he had a good friend, knowledgeable in "ballistocardiography", who wanted to spend time in an engineering and physics environment. As a result, Dr. N. Ty Smith from San Diego spent one year of his NIH Career Development Award in Utrecht. He is an anesthesiologist and an outstanding investigator and through his presence in Utrecht in 1970, I became interested in anesthesiology and... remained interested. During his stay in Utrecht we developed the first non-linear model of uptake and distribution of a single gas, halothane. A new concept was introduced with this model, i.e. that the presence of an anesthetic in different compartments of the body influenced the distribution of blood and cardiac output because it affected many parameters of the model. As will be pointed out, this is extensively used in the patient simulator for many more anesthesia compounds (4).
During that time Prof. Rideout was also spending a sabbatical in Utrecht; very stimulating! Partly overlapping, the physiologist Dr. Wilmer Nichols spent a stimulating year with us in Utrecht; now we regularly meet in Gainesville FL.!

Dick Bekkering meanwhile had initiated a part-time chair in medical electrical engineering in Eindhoven. The combination with his director's position in Utrecht made him decide to retreat. I was (and still am) very fortunate and honored to have been invited to become his successor. In 1973, I started as a part-time professor and from 1976 on it became a full-time position. During that time, I was asked by Prof.dr.ir. G. Vossers, the rector of the University, to see if I could bring together the many useful activities in the area of medical technology that were performed in practically all departments of the university.
I was very fortunate to have asked Prof. Jan Schouten, who had just retired as director of the Institute for

Perception Research (IPO) to help me do it. I was unexperienced in the university culture.
The indispensable spirit and working power of Tony Brouwers eventually resulted in BMGT, short for biomedical and health care technology, a coordinative body across all departments of the university and now one of the key research and development areas of the university. In 1984, we started the "Scientific Society BMGT" as a meeting place for clinicians, industry, and other workers in the health care field with investigators of the university.
The BMGT center, under the energetic influence of Ir. Jan Graafmans, successfully branched out towards gerontechnology (8) in 1987. A little more than a year ago, I initiated the Platform for Medical Technology ; I will come back to that a little later on.

Europe

A key activity, which has given me much satisfaction was my involvement with the Commission of the European Community (now Union). It started before 1973 with my membership of the CMSI (Committee Monitoring the Seriously Ill). An interesting detail is the following. Dr. Karl Gerbaulet, from DG XII, very much involved in and recognizing the importance of medical and health research for Europe, saw the opportunity to use biomedical engineering for that purpose. Health care was not mentioned in the Treaty of Rome in 1953. However, quality of life and all economic and industrial activities were heavily promoted. For Dr. Gerbaulet, this meant an opening: biomedical engineering was related to quality of life and to industrial development. This was the real beginning of the EU medical and health research program. Later, medical and health research became a recognized area of activities and part of the charter of the European Union. BIOMED I now is a program with a budget of 150 Million ECU and BIOMED II has grown to 133 Million ECU.
In 1980, the CMSI was merged with the Special Working Group Biomedical Engineering (5). Under a new management structure, this became the COMAC BME of which I was elected vice-chairman in 1982 and chairman in 1983. With the invaluable assistance of Dr. Walburga Skupinski and later from Dr. Viviane Thévenin both from the Commission, we saw the overall program grow and the BME activities develop from 3 to 30 projects within a network of 1200 European BME research centers by 1991, when I ended my personal involvement.
Why was this such fascinating work? It was enjoyable and rewarding to work with people who had a mission and who felt the urge to commit themselves to Europe. In the early eighties, we noticed that

most European investigators did not really know each other: they primarily knew their American colleagues. The projects were organized in the form of so-called concerted actions; research had to be paid for by the national governments and the CEC only paid for coordination, meetings and exchange of investigators and research material. In other words, we had to teach the Europeans who their colleagues were and how to cooperate among different national cultures. In the early years, much of our effort went into improving proposals (teaching people how to cooperate) rather than simply judging and turning bad ones down. It is rewarding to see that now, after almost 15 years, the interest in EU actions has grown so much that the Commission now has to deal with acceptability of rejection rates, imposing quality criteria, and a wider range of financing modalities. This is growth on a European scale and I am happy to have been in a position to contribute to it, jointly with Dr. Skupinsky and Dr. Thévenin. My gratefulness is directed to both the Division of Medical Electrical Engineering and to the University who let me do it, even though expenses were the only thing being paid for!

The networks, established under the COMAC-BME activities, were under the threat of being dismantled upon the ending of the 4th Medical and Health Research Program (8). That was one of the reasons that a group of former COMAC members founded the *EUROPEAN SOCIETY FOR ENGINEERING AND MEDICINE* (ESEM) in 1991 and made me president. Next month, we will have our 3rd biennial European conference, which will be held in Florence (I). A flourishing Elsevier journal *TECHNOLOGY AND HEALTH CARE* will soon enter its 3rd volume and is already INSPEC cited.

Anesthesiology

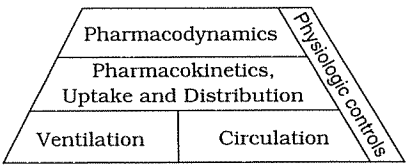
The presence of Dr. Ty Smith at the TNO Institute of Medical Physics in the early seventies and my subsequent interest in anesthesiology has already been mentioned. As a result, Ir. Hans Blom and I started to look at anesthesia control here in Eindhoven, jointly with the Anesthesiology Department of the Leiden University Medical School: Prof.dr. J. Spierdijk and Dr. A. Nandorff in particular. Being generously supported by Philips Medical Systems who supplied a complete monitoring set-up for the operating room (OR), at a time that most of the controls and measuring devices in the OR were still pneumatic(!), we succeeded to centralize all information about the patient in one location: essential from the ergonomic point of view and indispensable for improved supervision of the patient. This concept was also intensely promoted by Prof.dr. B. Smalhout from Utrecht. Signal analysis and

signal processing was (and still is) a central issue and jointly we performed a study financed by the European Commission on trend analysis (5). Dr. Allen Ream from Stanford University, upon recommendation of Dr. Ty Smith (7), came over for half a year in 1981. Apart from his anesthesiology task in Leiden he spent much of his time with us in Eindhoven discussing different modalities for an acceptable display of all relevant information about the patient.
In December 1986, much of this work and the study of its clinical effectiveness resulted in the graduation of Dr. A. Meijler. DADS was a central tool in this study and it subsequently served successfully for a number of years in clinical research in Leiden.
The magic monitoring matrix was conceived during that time and served on many occasions to explain the direction of our research.

Meanwhile, following another introduction by Dr. Ty Smith (6), we established a very prolific and above all close personal relation with Dr. J.S. Gravenstein. When we first met, he was chairman of the Anesthesiology Department of the Case Western University Medical School in Cleveland and later he moved to Gainesville FL to become graduate research professor at the University of Florida College of Medicine. In the department of anesthesiology he created a team of anesthesiologists and engineers second to none. From the beginning one of our graduates, Ir. Jan van der Aa, was one of the key people who brought many computer innovations into the working environment of the anesthesiologists. In 1983, very early on in their development, I was able to spend three months in Gainesville FL. During this time we developed a computer-simulation of the so-called BAIN circuit; a coaxial breathing circuit with complicated CO_2 removal. Using the multiple model approach developed in 1968 and an optimal segment size, we succeeded in duplicating the laboratory measurements in the model under a variety of circumstances. We then understood the mechanisms that govern the BAIN circuit.
The relation with Gainesville obtained a more permanent character through my appointed to adjunct-professor in the department of anesthesiology. Improving the quality of patient monitoring by applying engineering principles, was further pursued in the frame-work of "intelligent alarms". Could we extract more information from the primary available signals by a combined, integrated analysis?
In joint deliberations between Eindhoven and Gainesville it was realized that expert systems would be an ideal tool to execute this integrative information extraction. However, the available expert system approaches were much too slow in

their execution. This triggered us to find new ways, to open new avenues. While Ir. Hans Blom worked in Eindhoven on the development of the real-time expert system SIMPLEXYS, Ir. Jan van der Aa worked on feature extraction and rule development of a surveillance system for patients under artificial ventilation. The result: two Ph.D. defenses on a single day in May 1990.

Besides many other very interesting activities in Gainesville that involved students from Eindhoven, I want to mention the development of the Gainesville Anesthesia Patient Simulator. The original design by Dr. Sem Lampotang and Dr. Mike Good was based on a standard Ohmeda anesthesia machine. However, many frequently and, more importantly, infrequently occurring machine and human failures could electrically be activated (leaks, obstructions, valve failures) at any desired moment. While a manikin, "equipped" with an artificial lung was being ventilated and other anesthesia actions were performed following standard procedures, those failures were introduced and the time was recorded until the failure was identified. The usual monitors indicated the vital signs of the "patient". At this stage the simulator won a first prize at the scientific exhibit during the ASA meeting in Atlanta 1987.
We felt that a limitation of the simulator so far was that the effect of (in)adequate corrections by the trainee did not influence the vital signs readings. At that moment, the next version of the simulator was conceived; i.e. a comprehensive model would deal with the transport and distribution of oxygen and carbon dioxide and of the many different anesthetic drugs as well as with their effect on the blood circulation and the respiration. This was possible, once again, because of the 1968 publication on multiple modelling (4). A number of students from Eindhoven worked on the initial concepts. The project really got underway when Dr.ir. Wim van Meurs joined the Gainesville team (Fig. 2), after he finished his engineering and his Ph.D. work in Toulouse with Prof. J.-P. Morucci, at a position we found through the EC-COMAC connection.



Schematic representation of the interacting mechanical and mathematical physiologic models of the Gainsville Anesthesia Simulator (WVM, JEB, 1/17/95)

Figure 2

In December 1993, another memorable Ph.D. defense took place in Eindhoven, by Dr. Hans van Oostrom, also a pivotal person in the Eindhoven-Gainesville connection. His study dealt with another

aspect of patient monitoring and the engineering field of the information and signal processing. His central question was: Can we use a priori information to propose the setting of safe alarm limits for the monitoring of patients under anesthesia?

I think that the connection with Dr. J.S. Gravenstein and his Gainesville team with our division of Medical Electrical Engineering has been very prolific for both sides and I hope and expect that it will remain that way for a number of years to come.

The Division of Medical Electrical Engineering (EME)

The Division became an independent unit in 1980 and has operated very successfully in the Department of Electrical Engineering. We supervised close to 200 master students towards their engineering diploma and 10 students towards their Ph.D. In addition, the members of the Division accepted our responsibility and our share in departmental committees and management activities.

It may seem that many of my personal activities took place outside my home base, the Division. Yet, all these contacts opened up opportunities for my colleagues in the division.
Drs. Thijs Stapper, successfully directed the ultrasound imaging research of the division and supervised two Ph.D. studies in this field, in addition to numerous Master's studies. He was, and still is, one of the most highly appreciated teachers in a European course on biomedical engineering and medical physics in Patras GR. This course was initiated from within the COMAC-BME by Prof. B. Proimos from Greece, under the ERASMUS educational program of the European Commission.
Ir. W. Leliveld, nationally known for his research and development in the field of technical aids for handicapped people maintained a close relation with the Institute for Perception Research (IPO). This also resulted in two Ph.D. studies and a large number of Master's studies. He participated in workshops organized by Concerted Action teams under the COMAC-BME.
I already mentioned Dr.ir. Hans Blom and his work in the field of servo-anesthesia in relation with both the Leiden and the Gainesville cooperation. He, too, participated in concerted actions and as a teacher in the ERASMUS course.
Dr.ir. Pierre Cluitmans participated in the Leiden study, did one part of his Ph.D. research on anesthetic depth in Gainesville and another part in the Academic Hospital in Nijmegen with Dr. H. van Beem. Dr. Cluitmans is presently a key figure in an ongoing concerted action of the European Union on Post Operative Cognitive Dysfunction (8), par-

ticularly in elderly patients. This study, masterminded by Dr. J.S. Gravenstein, partially shaped by myself on the basis of my past experience in Brussels, encompasses 10 hospitals in different European countries. The project leader, Dr. Jakob T. Møller from Copenhagen, is an anesthesiologist and has extensive experience in such epidemiological studies. The subject is closely connected to the BMGT topic of Gerontechnology (8). The entire technical infrastructure for this European epidemiological study was designed and implemented by Dr. Cluitmans and his team and the central data collection and processing is presently in full operation in our division.
In 1979, the Division enjoyed the presence of Dr. Niilo Saranummi from Finland who continued with the study on trends in signals (5) with Dr. Blom. At the same time Dr. Frank Sasse (6), anesthesiologist from Madison Wisc. USA, took us further into this medical field.
For more than 10 years, the division worked closely with Prof. C. Brunia from the Brabant University in Tilburg. Aided by the Cooperating Center of the two Universities (SOBU), joint studies were performed on the localization in the brain of EEG signals, artifact reduction, and anesthetic depth using evoked and event related potentials in the EEG signal. Besides publications, the yield consists of 1 Ph.D. and 3 more to come shortly.

Something personal about the working atmosphere in the division of Medical Electrical Engineering deserves to be mentioned here. At times when my different obligations required more than I could give, it was never necessary to ask for help. My colleagues would come to me and say: we have the impression that there is a temporary overload: How can we help? What would you think if you would let us do ..... !
This attitude and friendship of all members from the division EME, has been so important and dear to me and has supplied me with much extra energy. Many thanks!

I hope that I have demonstrated the importance of being involved with and of keeping good relations with people to be able to fully exploit your own and other's abilities; in a multidisciplinary field, this mutual strengthening, while maintaining mutual respect, is absolutely essential.

Being a dean

During the past year, I have had the opportunity to serve as Dean of the Department of Electrical Engineering. For various reasons it had become necessary to restructure the entire department, which meant making choices that were not popular and not always well-understood, irrespective of frequent explana-

tions. The initial restructuring plans were designed with the help of much dedicated assistance from colleagues of the Department. Eventually, we decided that the final responsibility for the plan had be taken by the board of the department. During the months that followed, we spent many long extra meetings and we forged the final plan that was accepted with minor modifications by the council in December 1994. We also defined and discussed the Mission, Goals and Strategy which will help stabilize the future direction of the Department.
I want to express my appreciation and gratefulness to all my colleagues of the departmental management team for their dedication and mutual trust.
It goes without saying that the ordinary activities of the department had to continue in addition to the restructuring discussions. It was hard work, but we all did our share.
The regular meetings of the Council of Deans have been very constructive and instructive and evolved into a real team under the chairmanship of Rector J. van Lint.

The future

Medical technology has developed into a specialization that has become indispensable for the delivery of the quality of health care we are used to in the western world. A major development has never yet been turned back.
Irrespective of the discussions about and criticisms on medical technology in our society, it has become an absolute necessity. Just think about preventive medicine without properly conducted epidemiological studies; primary care without diagnostic centers and computer networks; clinical diagnostics without advanced imaging techniques, without devices for measuring heart and brain activities; treatment without biochemical and drug research; surgery without anesthesia and patient monitoring; post-operative care and rehabilitation without technical aids.
For much of the necessary research and development in these fields, qualified engineers are needed who are trained both in their engineering skills and sciences and in multidisciplinary thinking and acting. For these reasons, I hope and expect that our University will continue to contribute both by education and by research to this fascinating and challenging field.

Nobody knows what the future will bring for the individual, but we need to make plans. I am, therefore, very pleased with the opportunity to maintain ties with the division of Medical Electrical Engineering. It has been my university home for more than 20 years and hopefully for some more. I also look forward to continuing my relation with Anesthesiology Department in

Gainesville for our mutual benefits and enjoyment.
An activity that I briefly mentioned earlier concerns the *Platform for Medical Technology.* Already in 1982, while giving the Dies lecture, I gave some suggestions about improving relations between university and industry. I remained interested in this subject, which eventually led to this platform. The idea behind this Platform for Medical Technology is to primarily generate ideas, projects and products that are required by the medical and health care community; in other words, to activate a "market pull" rather than a "technology push" that does not always lead to an application. I am convinced that technology transfer has a much better chance if it has to deal with real and properly identified problems.
The Platform consists of a core group with representatives from primary care, hospitals, insurance companies, industry, the Eindhoven University of Technology and the engineering college here in Eindhoven (HS-E). In this core group we regularly discuss the feasibility of new ideas and requests. Based on subsequent feasibility studies, new projects are formulated, research and development initiated at the university or the college, consortia of industries formed, and professional project management is offered. Over the past year, Ir. Dirk van den Berg from NEHEM Consulting Group has been the primary drive behind the whole of its activity because of my duties as Dean. I look forward to spending more time with him in these activities and to further explore the potentials of this approach towards a University Technological Institute (UTI).

The future of the Department of Electrical Engineering and of the entire University are closely linked with the direction of political thinking. It is easy, and probably right, to blame the politicians for a lack of insight into and understanding of university management and its means for quality control. On the other hand, we need to supply adequate information to them and to the whole of society and demonstrate that our university is up to date, has high teaching and research standards and is continually in the process of adaptation and improvement. If we as an university don't deliver this message ourselves, it will not be delivered; nobody will do it for us. In other words, the future of the Department of Electrical Engineering and of the entire University is in our own hands.
One of the major necessary changes at our University, to my opinion, is a much higher appreciation for those who succeed in explaining the relevance and quality of our work to an audience wider than the circle of their colleagues. I know that this is not an easy task, it is time-consuming and requires spe-

cial skills. But the worst part is that such activities do not earn any credits (in terms of appreciation and encouragement). We live close to the beginning of the 3rd millennium and we cannot carry on with a university concept of the 19th century!! The university is no longer a specialized, isolated, ivory tower. We need to be recognizable and appreciated by society through our contacts and products; we are a public organization and with responsibilities to that self-same society. We urgently need to change our attitude towards society; we are completely dependent upon it!

With this strategy, we can convince potential students that it is more than worthwhile and personally satisfying to study (electrical) engineering. We should make clear to them that a university study should not be taken lightly. The autonomous financial support to our students over the past years has been granted without much emphasis on the responsibility that went along with this right.
If this financial support is reduced in the coming years, because society can no longer afford to give students the right to free education without the obligation to dedicate much of their energy and attention to study, this may reduce the number of students enrolled, but may improve their motivation. There is nothing wrong in admitting that money is a prime motivator.

Conclusion

Words of thanks in the first place go to my family. My wife Truus and the children Ingrid, Margot and Lukas have followed my activities over the years with great interest, even though my absence has not always been easy for them. The special interest and involvement of my wife with my activities can be concluded from the many logos she skillfully designed for the different activities I was involved in; some were chosen in competition with other designs.

I also thank the Division of Medical Electrical Engineering for the trust and the wonderful atmosphere over all those years. I am convinced that under the leadership of Dr. Pierre Cluitmans, the division will have a bright, interesting and stimulating future, and will open new and challenging avenues.
The symposium which the Division organized today for this occasion under the title: *"Medical Technology: Building Bridges towards a New Century"* with many prominent speakers is an illustration of the wonderful spirit and potential that is present in the Division.

I thank the Department of Electrical Engineering and the Board of the University for the many opportunities given to me and the support I received to realize some of my ideas.

Finally, thanks to the people I mentioned so far, and thanks to all those I could not mention in the limited time available. What would have become of me without the opportunities to share so many thoughts and feelings with you and to discuss scientific problems and their solutions.

Thank you very much and may God bless you.

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Jan E.W. Beneken was born in Arnhem in 1934, where he finished high school (HBS-B) in 1952. He graduated in electrical engineering from the Delft University of Technology in 1958. After serving as officer in the Royal Dutch Navy he joined the TNO Institute of Medical Physics in 1960.
In 1965 he defended his Ph.D. thesis on cardiovascular modeling at the University of Utrecht and subsequently he spent a year as post-doctoral fellow of the United States Public Health Service with Dr. A.C. Guyton in Jackson Miss.. During the fall-semester of 1967, he was visiting associate professor at the University of Wisconsin in Madison Wisc. in close collaboration with Prof. V.C. Rideout.
In 1973 he became part-time professor in Medical Electrical Engineering at the Eindhoven University of Technology and in 1976 this became a full-time position. He participated in the establishment of the BMGT (biomedical and health care technology) organization of the University and worked with the Commission of the European Community (Union) to advance European cooperation in medical technology.
He wrote over 150 publications, supervised close to 200 master students and more than 10 Ph.D. studies.
As adjunct-professor in the Department of Anesthesiology of the University of Florida College of Medicine he established over the past 11 years a close cooperation between that department and the Division of Medical Electrical Engineering at Eindhoven.
The last 14 months before his early retirement as full-professor he served as Dean of the Electrical Engineering Department at Eindhoven University of Technology.