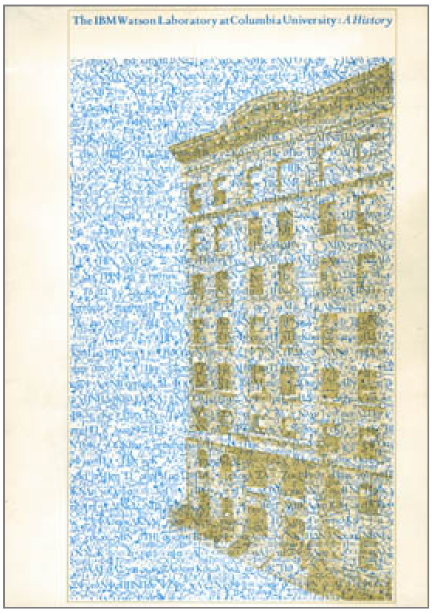
The IBM Watson Laboratory at Columbia University
A History

by Jean Ford Brennan
with the archival assistance of H.K. Clark



Cover: Click to magnify

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Armonk, New York
February 18, 1971

This book is filled with bright people who made IBM history—and computer history. The Watson Laboratory has meant a great deal to the IBM Company over the years, and I am delighted that we have this record of the many contributions of its people.

(Signature of Tom Watson, Jr.)

(ORIGINAL COPYRIGHT PAGE)

The text in this box is not part of the original work. This book was scanned and converted to HTML for the Web by Frank da Cruz of Columbia University in August 2003 for the Columbia University Computing History Project in the very building that is pictured on the front cover**:** Watson Laboratory at 612 West 115th Street, New York City. The original text was not altered in any way (unless by accident); the formatting is close in spirit, but not identical. Original page numbers are shown inline as [-*xx*-] and the Table of Contents and Index are live. Click on images to view full-size versions (which, like those in the book, are small). All links from this page (except in this box) are either internal or to pages that are part of this work (i.e. images or HTML wrappers for images). **All further commentary on this work is in a separate document;** CLICK HERE to read it. *This page was updated to HTML5 in February 2021 and also adjusted for fluidity so it can display properly on narrow screens. The maximum width was changed from 100% to 800 pixels for easier reading on wide screens. The HTML was validated at https://validator.w3.org on 27 February 2021 with no errors or warnings.*

Thanks to Bruce Gilchrist, Director of Computing at Columbia from 1973 to 1985, for donating this book to the Columbia Computing History archive.

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Frontispiece: The building at 612 West 115th Street, New York City, which housed most of the Watson Laboratory activities from 1953 to 1970.

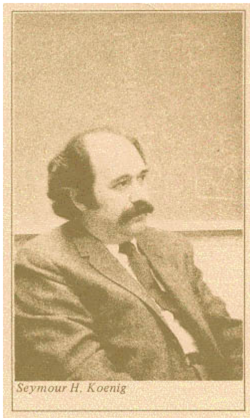
Foreword

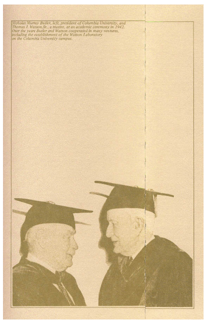
As one goes through graduate school, and learns the lore of physics, certain names and associations become automatic. Two that come to mind are the Thomas factor (a key to understanding the fine structure of atomic spectra) and the Wentzel-Kramers-Brillouin approximation (a mathematical link between classical physics and the more recent quantum physics.) Imagine, then, being interviewed by both Drs. Thomas and Brillouin for a post-graduate position at the Watson Scientific Computing Laboratory at Columbia University. Most impressed, I accepted the position, offered late in 1951, and have been at the Laboratory ever since.

To document the history of such a Laboratory is very difficult. The story must be accurate without being pedantic, it must be cohesive when describing the history. I feel that this has been admirably achieved. The main credits must go to H. K. ("Ken") Clark, who for twenty-five years has accumulated and preserved the photographs, documents, announcements, clippings and assorted material which so often become important only in retrospect, and to Jean Ford Brennan, of the scientific information department at the Thomas J. Watson Research Center. Through interviews, archival recordings and Clark's collected memorabilia, Mrs. Brennan has described the history of the Watson Laboratory at Columbia University as well as the extensive earlier relationships between IBM and Columbia in an eminently readable and informative manuscript.

The Laboratory was six years old then. Now, in 1970, it is in its twenty-fifth and final year. During the quarter-century, a remarkable range of professional interests was pursued at the Lab. The world's then most powerful computer (the NORC) was designed and built; the orbit of the moon was computed with ever-increasing precision; the Michelson-Morley experiment was repeated – and improved by two orders of magnitude – using the then newly-developed ammonia maser; an attempt was made to grow diamonds and to store information in "Wildroot Cream Oil;" the mysteries of photosynthesis were explored and the behavior of matter near absolute zero was studied; and the structure and function of many blood serum proteins were investigated. The diversity, the quiet competence, the style, the personalities, and the scientific successes at the Watson Laboratory have been sources of great satisfaction for many of us over the years.

Seymour H. Koenig, Director
IBM Watson Laboratory
at Columbia University   August 18, 1970





Nicholas Murray Butler, left, president of Columbia University, and Thomas J. Watson, Sr., a trustee, at an academic ceremony in 1942. Over the years Butler and Watson cooperated in many ventures, including the establishment of the Watson Laboratory on the Columbia University Campus.

Introduction

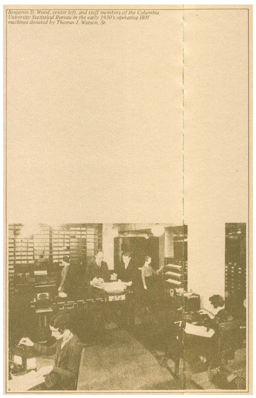
On February 6, 1945, headlines across the front pages of New York City newspapers proclaimed the fall of Manila to American troops of the Sixth and Eighth Armies. With the end of World War II in sight, reports from the battlefronts dominated the news. Almost unnoticed on the back pages that day was a joint announcement by Nicholas Murray Butler, president of Columbia University, and Thomas J. Watson, Sr., president of International Business Machines Corporation, that a new facility to be known as the Watson Scientific Computing Laboratory at Columbia University would be established in a building on Morningside Heights and equipped with IBM machines to "serve as a world center for the treatment of problems in various fields of science whose solution depends on the effective use of applied mathematics and

To those in the know, however – which is to say a few university professors, a small group of engineers in industry associated with them, and certain scientists working on secret war projects – the announcement that Columbia and IBM planned to probe the peacetime potential of automatic calculating machines in solving scientific problems had highly interesting overtones. It was not, on the other hand, altogether a surprise. The university and the company had enjoyed a close association, extending back over fifteen years, that had few – if any – counterparts elsewhere in the country. For IBM, the association afforded a window on the academic world, where educators and scientists worked in fields that offered interesting possibilities for the use of calculating machines. For Columbia, the liaison provided convenient access to the machines and an opportunity to keep abreast of developments in an mechanical calculations."

It is doubtful if more than a handful of readers knew what a "computing" [-2-] laboratory was; indeed the word itself was unfamiliar to most. For although it was known that a few large automatic calculating machines had been built during the war and assigned to military projects of various kinds, there was very little general understanding of how these machines worked, what their capabilities were, or how they differed from the accounting machines that had been on the market before the war.

industry that appeared to have important implications for research in education, science and even the humanities.

The story of the Watson Laboratory is thus a part of the larger story of the unique, on-going Columbia-IBM relationship, whose fruits over the last forty years – in terms of educational and scientific projects undertaken, new theoretical concepts advanced, scientists recruited, pioneering machines built, students taught and specialists trained – have had far-reaching effects on the development of the art and science of computation in the United States.



Benjamin Wood, center left, and staff members of the Columbia University Statistical Bureau in the early 1930s operating IBM machines donated by Thomas J. Watson, Sr.

[-3-]

Columbia University Statistical Bureau (1928-1933)

In the fall of 1928, Thomas J. Watson, Sr., president of IBM, received a letter from Benjamin D, Wood, head of Columbia University's Bureau of Collegiate Educational Research, describing his pressing need for some automatic method to replace the laborious hand-scoring of examination papers involved in large-scale testing programs. The letter was one of ten that Wood had sent to the heads of the country's largest office machine companies. Unlike the other recipients – some of whom did not even bother to reply – Watson was interested enough to telephone Wood and give him an appointment of exactly one hour in which to advance his case. At the meeting, which took place at an exclusive club in New York, "a secretary [-4-] was posted to remind Watson when the time was up. Wood's ideas about the potential uses of machines in education, especially the possibilities of electronic a data processing machines (a figment of a Wood's imagination at that early date) so appealed to Watson that he kept Wood talking the entire afternoon. Every hour on the hour the secretary was waved away."[1]

The "Columbia Machine" was installed in 1931, and soon word of the facilities at the Statistical Bureau began to spread across the country. A Columbia alumni publication reported: "No two jobs are alike in this interesting workshop. The Rockefeller Foundation comes along with a new problem one day and the next day a publisher or economist brings in something different. Among the clients of the Bureau are, besides Columbia and the Carnegie (Foundation], Yale, Pittsburgh, Chicago, Ohio State, Harvard, California and Princeton."[2]

Meantime, Wood and his assistants were working with IBM's engineers to solve the original problem of developing an efficient automatic test-scoring machine. After attempts to develop IBM's tabulator-punch card technique to the purpose proved unsuccessful, it was decided to concentrate on developing a machine to take advantage of the fact – known to generations of schoolboys – that pencil marks can be good electrical conductors. The plan was to build into a machine tiny electrical circuits that would be completed by the presence of pencil marks at given places on an answer sheet – thereby automatically recording a score. The

Wood's eloquence was handsomely rewarded. Watson made him an IBM consultant (a post he held for 28 years) and ordered three truckloads of tabulating, a card-punching, sorting and accessory equipment dispatched to special quarters Wood had wangled In the basement of Hamilton Hall, where the Columbia University Statistical Bureau began operations in June, 1929. During the next few months, the IBM machines were kept busy not only by the Statistical Bureau, which used them to make detailed analyses of hand-scored test results, but also by various academic departments of the university. In particular, the Astronomy Department found the machines helpful for the interpolation of astronomical tables. By 1930, Watson was sufficiently impressed by these novel uses of IBM equipment to authorize the company's manufacturing plant at Endicott, N.Y., to develop a special tabulator, requested by Wood, to enable the Bureau to make even more complex calculations. Known variously as the "Columbia Machine," the "Statistical Calculator" and "Ben Wood's Machine," the new unit mass-produced the sums of products by the method of progressive digiting and read punch cards at the rate of 150 per minute. It contained ten 10-position counters with provision for shifting totals internally from one counter to another – a capability that anticipated a future function of computers.

theory was promising, but there was a serious practical problem: the amount of electricity conducted – therefore the score recorded – varied widely with the degree of darkness of the pencil marks.

In 1934, just as this problem was beginning to appear insoluble, a high school teacher in Ironwood, Michigan, named Reynold B. Johnson (now an IBM Fellow) came up with the answer. Johnson had been working independently for several years on a test scoring machine based on the pencil-mark principle. Knowing of Wood's interest in the field, he sent a description of his design to Wood, who saw that Johnson, by introducing two-million ohm resistors into the electrical circuits in his machine, had raised the total resistance to the point where variations in the pencil marks no longer mattered.

On the strength of Wood's enthusiastic recommendation, Johnson was invited to come to New York in the summer of

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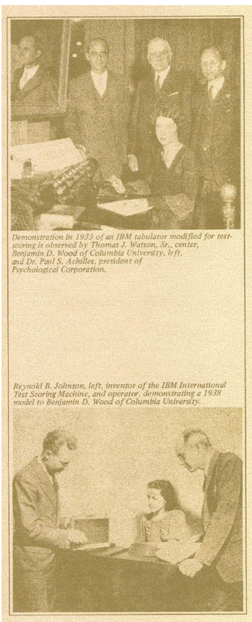

Top: Demonstration in 1933 of an IBM tabulator modified for test-scoring is observed by Thomas J. Watson, Sr., center, Benjamin D. Wood of Columbia University, left, and Dr. Paul S. Achilles, president of Psychological Corporation.

Bottom: Reynold B. Johnson, left, inventor of the IBM International Test Scoring Machine, and operator, demonstrating a 1938 model to Benjamin D. Wood of Columbia University.

1934 to explore with IBM representatives the possibility of the company's developing a model of his machine. Johnson has given an account of his visit. "After several weeks of conferences, [I] was

Hired by IBM in the fall of 1934, Johnson was sent to Endicott, where he found himself one of the few inventors in the group with a college degree, and one of the first to be brought in from outside the company.

called in to meet with a group of IBM executives who announced that they had come to the decision that this test scoring machine was an incomplete invention in which they had no further current interest... Fortunately for me, however, the next day Dr. Ben Wood got in touch with Mr. Watson, who was vacationing in Maine, and assured him that the invention under consideration was a sound one and that the inventor who went along with it was probably worth investing in too. Within a couple of days, IBM decided to go ahead with the development..."[3] To company salesmen who warned that the machine would never be a money-maker for the company, Watson is said to have replied: "Who wants to make money out of education?"

Over the years, many IBM machines had been developed by talented men who had come up through the ranks from work bench and drafting board – a fact of which Thomas J. Watson was proud. Wide-spread recruitment of scientists and engineers at IBM was unheard of, and indeed did not start until after World War II, when – as in Johnson's case – members of the Columbia University faculty were to play a key role. Johnson's initial assignment was to work on the machine that became the IBM Model 805, the International Test Scoring Machine, officially announced in 1937. Although the 805 never found a large market, it made possible a major breakthrough in large-scale testing programs in the U.S., including those used in World War II to assist in the placement of recruits.

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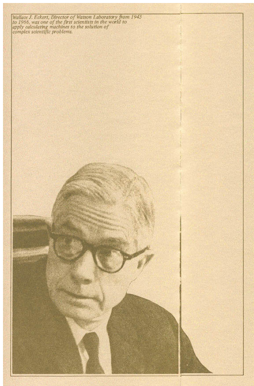

Wallace J. Eckert, Director of Watson Laboratory from 1945 to 1966, was one of the first scientists in the world to apply calculating machines to the solution of complex scientific problems.

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Astronomical Computation (1934-1945)

Pioneering work by Eckert

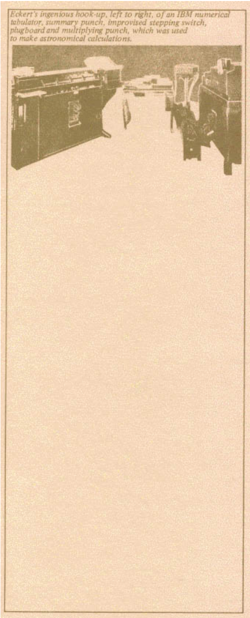
Eckert studied the machines and then worked out for himself a control system using a plugboard and relays borrowed from the "Columbia Machine" – whose use

An interested visitor to the Columbia Statistical Bureau in the early 1930's was Wallace J. Eckert, a young astronomy professor who frequently wandered over from the University's Rutherford observatory on top of Pupin Hall to watch the IBM machines at work on astronomical tables. One day, Eckert began to speculate on the possibility of making even more advanced scientific calculations with machines. He knew that the British astronomer L.J. Comrie had already applied punch card methods to the "Tables of the Moon", which had been painstakingly worked out over a lifetime by Professor E. W. Brown of Yale University. He also knew that IBM had recently announced a new series of business accounting machines including a multiplying punch (the first IBM machine capable of forming products directly instead of by repetitive addition); a direct subtraction tabulator; and a summary punch. It occurred to him, as he wrote later, that "the time was now ripe for the establishment of a scientific laboratory of a revolutionary nature. Whereas it had been possible in the past to accomplish important results by ingenious manipulation of the sorting and adding operations, there now were available all the necessary units for a laboratory which would automatically perform the most laborious calculations encountered in science..."[4]

Having learned through Wood of Thomas J. Watson's interest in the use of IBM machines for educational and scientific purposes. Eckert determined to [-8-] draw up a list of equipment needed to create the kind of laboratory he envisioned and to submit it through Wood to IBM. The time was 1933 – the bottom of the depression – and some items on Eckert's list called for substantial modifications of standard IBM machines to make them sufficiently flexible for scientific operations. Nevertheless, Watson – who had become a trustee of Columbia – once again gave the go-ahead, and within a few weeks the machines were delivered to the attic of Pupin Hall. In addition to a full set of the latest IBM accounting machines, there was a special Model 601 Multiplying Punch capable of doing direct interpolation – a very unusual feature, especially designed for Eckert by one of IBM's top engineers at Endicott. Watson's attitude toward this and subsequent donations of equipment to Columbia, was summed up in a statement made later in his life; "Our motto down through the years has been and will continue to be 'There is no saturation point in education'. We have always placed special emphasis on this in our scientific development..."[5]

had been discontinued earlier – to make interconnections between the units of equipment. In devising this scheme, Eckert took an important step into the twilight zone that separated the calculators of those days from the concept of the computer. Of his control system, Eckert recalls: "All of the connections between the machines were pluggable and had switches so that in ten minutes we could convert them back to their normal form and use them for batch processing or hook them together as a system and use them for something like numerical integration, which had to use the whole set-up. The programming of the assembly as a computer was a mixture of mechanical [devices] and punched cards." The control box had settings that told the different machines what they should be doing at a given time and these gave the broad mechanical programming of the problem. The punches on the cards were used to program the specific details. "It was a revolutionary thing, because up until that time general scientific computing always involved hand work. The numbers had to be copied. The arithmetic had to be done at best with a desk calculator or with logarithms, and here for the first time you could do general things such as the solution of a differential equation completely automatically and you never had to read or write a number."[6]

The new laboratory – the only one of its kind in the world – began operating early in 1934 under the aegis of the Columbia Astronomy Department. To members of the department and to graduate students, one of the most interesting projects Was the use of the machines to solve the differential equations of planetary motion by numerical integration. With the method, a number of highly accurate orbits extending over long periods of time were obtained. Concurrently, several large data-reduction programs were undertaken. For the Yale University Observatory, which was constructing a photographic star catalog, the laboratory took over the laborious task of converting from spherical to rectangular coordinates for thousands of stars. For Columbia's own program in photometry, involving about 150,000 stars, the machines were used to calculate the coordinates of stars on photographic plates, record photometer readings, perform the numerical reductions, and make a listing of all the final data – an enormous task. The laboratory also put onto punch cards astronomical data from the Boss Catalog of 30,000 stars. From the card sets, statistical data of many kinds Could be derived by simple sorting and tabulating operations. Easily duplicated, the card sets could also be made available to other users.



Eckert's ingenious hook-up, left to right, of an IBM numerical tabulator, summary punch, improvised stepping switch, plugboard and multiplying punch, which was used to make astronomical calculations.

In the mid-1930's, however, so few observatories had access to punch card equipment that C. H. Tomkinson, manager of the IBM Commercial Research Department, suggested the formation of a new, non-profit organization under the auspices of the American Astronomical Society to make the laboratory's facilities available to astronomers generally. The result was the Thomas J. Watson Astronomical Computing Bureau,* established in 1937 as a joint enterprise of the Society, the Department of Astronomy of Columbia and IBM. Members of the original board of managers included the chairman, E. W. Brown, emeritus professor of Yale University's Mathematics Department and creator of the monumental "Tables of the Moon"; Henry Norris Russell, director of the Princeton Observatory; T. H. Brown of the Harvard University Business School; C. H. Tomkinson of IBM; and Wallace Eckert, who was to serve as acting director of the Bureau.

Under the new arrangement, the managers had the power to pass on all applications for the use of the Bureau's equipment and to charge appropriate fees for projects accepted. To assist visiting astronomers whose projects passed muster but who had no experience in using punch card methods, Eckert prepared a guidebook, revered by its users as "the Orange Book" because of its bright cover, which may have been the first – and was surely the most widely-distributed – text of its kind available to scientists at the time.** Not surprisingly, the visitors, having mastered the "Orange Book" and the machines, were extremely reluctant to return home to the use of desk calculators. As a result, there began a rising demand by observatories for equipment similar to that at Columbia.

By the late 1930's, the attic of Pupin Hall had become a cross-roads for visiting scientists who came to inspect the Bureau's versatile machines. Among them

* An earlier title. the Astronomical Hollerith-Computing Bureau. was superseded after a few months.
***Punched Card Methods in Scientific Computation*, W.J. Eckert; The Thomas J. Watson Astronomical Computing Bureau. Columbia University. 1940.

was Howard Aiken, a mathematics teacher and candidate for a doctoral degree in physics, who was working at Harvard on plans for a machine to solve differential equations that were involved in his thesis. Aiken had heard of the Bureau through T. H.

Eckert's first assignment was to design an air almanac to be used by navigators of the rapidly expanding U.S. Air Force. The need for improved navigational aids had become increasingly important as Allied shipping losses to enemy submarines continued to increase. Eckert

Brown, a member of its board of managers, and one day in the fall of 1938 he came to Pupin Hall to see the IBM machines. Eckert showed him around, listened to his ideas and suggested that he try to interest IBM in his project.

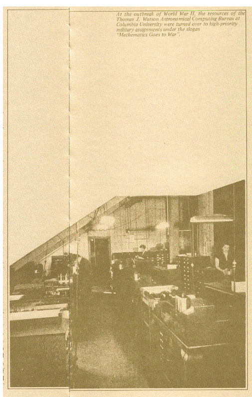
What happened thereafter is a well-known chapter in computer history and is outside the scope of this account. However, to summarize briefly: Aiken's plans proved so interesting that in 1939, IBM decided to develop and construct the machine, known as the Automatic Sequence Controlled Calculator. Built at Endicott during the next five years, the huge electromechanical machine was the first automatic general-purpose computer. In 1944, it was presented by IBM to Harvard, where it was initially lent to the U.S. Navy for classified work.

The War Years

In 1939, the office of the Director of the Nautical Almanac at the U.S. Naval Observatory in Washington became vacant and Wallace Eckert was invited to accept the prestigious position. Eckert, who was well aware of the growing interest in automatic calculating equipment among U.S. observatories, realized that at the Naval Observatory, he would have the opportunity to mechanize one of the largest computation centers in the country. He accepted the post and early in 1940, reported to the Nautical Almanac Office. He recalls: "They had no automatic equipment. Every digit was written by hand and read and written repeatedly... They didn't have a machine that would print figures automatically. They had desk calculators."[7]

realized that a navigator's job could be greatly simplified and speeded up if the data he needed were pre-calculated. Before such data could be computed, however, astronomical tables of various kinds had to be created. Drawing on his experience at the Columbia laboratory, Eckert determined that the table-making function could be handled most efficiently by standard IBM equipment operating in batch mode. He ordered – and quickly received – the necessary machines, including an alphanumeric tabulator with sexagesimal (base 60) counters for hours, degrees, minutes, seconds and decimals of a second. With the equipment, the Almanac office was able to create the necessary tables, use them to compute in advance precise astronomical data for each day of the year, and print the data without human intervention of any kind. With the data, navigators could obtain fixes of their positions within about one minute, compared with 30 minutes by ordinary methods. By enabling planes to locate targets and strike much more quickly, the air almanac contributed importantly to the subsequent decline in the loss of Allied ships in the early stages of the war, before the use of radar.

Eckert's mechanization of the Nautical Almanac within a period of only a few months did not go unnoticed by other agencies of the armed forces. Computing laboratories patterned on those at Columbia and the Naval Observatory were soon established at the Aberdeen Proving Ground, the Los Alamos Scientific Laboratory and more than a dozen other strategic locations around the country. The Thomas J. Watson Astronomical Computing Bureau itself was turned over to war work in 1942, and was expanded to fill the top floor of



At the outbreak of World War II, the resources of the Thomas J. Watson Astronomical Computing Bureau at Columbia University were turned over to high-priority military assignments under the slogan "Mathematics Goes to War".

Pupin Hall, where the machines, under the supervision of Dr. Jan Schilt, Director of the Rutherford Observatory, worked on ballistic

In the fall of 1944, Thomas J. Watson, realizing that IBM now needed scientists in order to keep abreast of the technological developments in the field, invited Eckert calculations and other high priority military assignments.

By the mid-1940's, developments in computer technology were coming thick and fast. The ASCC machine had been completed and placed in operation at Harvard. Other advanced electromechanical machines – including IBM relay calculators capable of multiplication of harmonic series, matrix multiplication and solution of 6th order differential equations – were developed and rushed into service. At the Moore School of the University of Pennsylvania, the first computer with vacuum tube components, the ENIAC*, was being built and plans for a computer of even more advanced design were in the wind there.

* Electronic Numerical Integrator and Calculator.

to join IBM as director of a new Department of Pure Science, and to assemble a staff with outstanding scientific qualifications. In the discussions that followed, Eckert proposed that the most advantageous location for such a department would be at a laboratory on the Columbia campus, where scientific research could be carried on in an academic setting and where contact could easily be made with visiting scientists as they passed through New York City. Implicit in the plans for the future was the design of a new, powerful calculating machine, in which both Watson and Eckert were interested. Eckert found the prospects sufficiently exciting to forego his career post at the Naval Observatory and return to New York to join IBM in March, 1945 – a few weeks after the formal announcement of the establishment of the Watson Scientific Computing Laboratory at Columbia University. He was the first scientist at the Ph.D. level to be hired by IBM.

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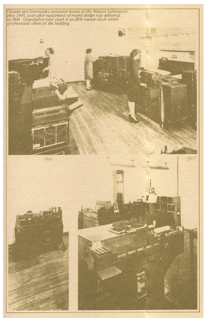

Upstairs and Downstairs computer rooms of the Watson Laboratory circa 1946, soon after equipment of recent design was delivered by IBM. Grandfather-type clock is an IBM master clock which synchronized others in the building.

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Watson Scientific Computing Laboratory: Mission I (1945-1952)

Applied Mathematics and Computational Theory

From all accounts then, it appeared that the Watson Laboratory was to have as its major mission the exploration of the use of applied mathematics and

Thomas J. Watson's concept of the international, public-spirited role that the new laboratory was to play is revealed very clearly in the wording of the official news release. "The research and instructional resources of the laboratory will be made available to scientists, universities and research organizations in this country and abroad, and special cooperative arrangements will be made with scholarly institutions," it read. The laboratory, to be directed by Eckert, "one of the first to realize in actual practice the potentialities of the IBM machines for the rapid solution of highly complex mathematical equations used in scientific research," was to engage in a joint program of research instruction with Columbia, "utilizing for this end the personnel and facilities of both institutions." Moreover, consulting services of the scientific staffs of both IBM and the university, as well as those of prominent figures from the academic world at large, were to be made available. In short, "the laboratory is designed not only to increase the already notable contribution of high efficiency calculating machines to the war effort, but by a broad interest in the computational problems of all branches of the physical and social sciences to strengthen the scientific and educational foundations of our national security and the welfare and peace of the world."

The news release made no mention of plans for the laboratory to design anew calculating machine. However, a [-14-] newspaper reporter who visited the Columbia campus in search of material for a feature story on the new "figure factory" – as the press dubbed it – filled out the picture in a report that reflected the public's attitude toward computers at the time. After looking over the machines in Pupin Hall, he wrote: "I asked why... isn't it possible to put an income tax return in one of the slots of those dang-fangled modern devices and watch it come out solved, sealed and ready for delivery on March 15." Less ingenuously, he commented: "Columbia eventually hopes to manufacture a calculator that will shame the 51-foot mechanical marvel at Harvard..."[8]

Another function of the laboratory not fully spelled out in the initial announcement was the instruction of Columbia students by laboratory staff members, who would have non-salaried appointments to the university faculty. Courses, for which academic credit would be given, were to be offered by staff members in mathematics, physics, astronomy and other fields under the auspices of various departments of the university. Eckert himself, appointed Professor of Celestial Mechanics at mechanical calculation to solve scientific problems of all kinds. Beyond that, it was to assist visiting scientists and others in the mastery of machine methods and techniques, design new machines, and instruct students in computational science. Eckert began his formidable assignment as director by addressing two pressing problems: equipping the laboratory, and recruiting personnel to staff it, while waiting for alterations to be completed on the laboratory's new quarters – a 5-story former fraternity house at 612 West 116 Street – he established temporary headquarters at Pupin Hall and began to assemble units of the latest machines from Endicott. These machines were later moved to the new quarters where they were reinforced by two of the powerful IBM relay calculators of the type built for the Aberdeen Proving Ground, a new multiplying machine with vacuum tube components, and electromechanical multipliers of several kinds (known only by such code names as Nancy and Virginia). Of special interest was an experimental model of a fast arithmetic processor, which Eckert attached to an accounting machine. Instead of being programmed through wiring on the control panel, the machine was controlled by coded punches on cards. The result was an early form of sequence calculator that anticipated IBM's famed Card Programmed Calculator. With this equipment, the laboratory tackled problems brought in during the closing months of the war by scientists associated with the top secret work of the Manhattan Project and elsewhere. One such visitor, with whom a fruitful alliance was to develop, was John von Neumann, an eminent mathematician and perhaps the most knowledgeable man in the country on the art of computing.

As the war drew to an end, Eckert – with the aid of John C. McPherson, IBM Director of Engineering, who took a keen interest in the work of the laboratory – began the recruitment of specialists in areas of prime importance to the laboratory: applied mathematics and computational theory. As a distinguished scientist in his own right, a full professor at Columbia, and head of a department at IBM, Eckert was in an advantageous position to negotiate with other scientists. Moreover, he had evolved a philosophy about the role of the laboratory that proved extremely attractive to scientists eager to return to peaceful pursuits. Members of the Pure Science Department at the Watson Lab were to be full-time scientists, free to do individual research

Columbia in 1946, became the first Watson Laboratory staff member to assume teaching duties. There were to be many more as time went on.

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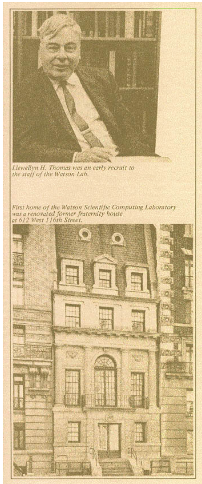


Top: Llewellyn H. Thomas was an early recruit to the staff of the Watson Lab.

Bottom: First home of the Watson Scientific Computing Laboratory was a renovated former fraternity house at 612 West 116th Street.

just as at a university. They would not be tied in to large developmental projects, and indeed, would be discouraged from building up large staffs in connection with their own work. They could teach if they wanted to – but only without pay. There was to be no "moonlighting". They could enroll in courses if they wished, work toward advanced degrees, or work at pure science.

By emphasizing the freedom at the laboratory, Eckert struck a profoundly responsive chord in the people he approached. One of his earliest recruits was Robert Rex Seeber, who had been at the Harvard Computational Laboratory, where he worked with Howard Aiken on the ASCC machine, and was burning with ideas of his own on how a computer should be designed. Another was Herbert R. J. Grosch, who had been employed as an optical engineer in defense industry and was eager to return to research. On the advice of Professor I. I. Rabi of Columbia's Physics Department, Eckert approached Llewellyn H. Thomas*, one of the foremost applied mathematicians in the world, who agreed to come to the laboratory from Ohio State University in order to work on the adaptation of mathematical problems to the powerful new calculating machines. (Since Thomas did not seem to fit into any standard job category, the employment department placed him on the payroll as a technician.)

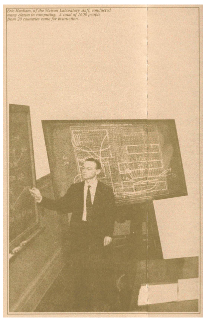
When it shortly became clear to Eckert that he also

Since the start of 1945 – under a directive from Thomas J. Watson – [-16-] discussions had been taking place between IBM officials, inventors and engineers from Endicott, and staff members of the Watson Lab as to the type of new giant calculator that IBM should build. It was generally agreed that the machine should be electronic and that its speed, storage and capabilities should substantially exceed those of the ASCC machine at Harvard. But there were to be differences, too. Eckert, Seeber and others presented the case for an ideal machine – one with a very fast arithmetic unit, with sequential control of the storage and flow of data, and with the fullest possible use of electronic components. Frank Hamilton, the engineer who had built the ASCC machine, and other engineers and inventors emphasized the complexities involved in such a machine organization and the reliability problems raised by the use of great numbers of vacuum tubes. By December, the two points of view were reconciled in a compromise recommendation that IBM build the Selective Sequence Electronic Calculator, with both electromechanical relays and vacuum tubes. Eckert, who had been charged with the responsibility of establishing the fundamental specifications of the machine, wrote a description of the logical organization and the overall plan; vacuum tubes were to be used in the arithmetic unit, in the control circuitry and in part of the storage where speed would be most useful; relays were to be used for main storage, traffic controls and elsewhere. The mode of operation of the machine was to be determined by removable plugboard units.

needed to bring in electronics specialists knowledgeable about the radical wartime developments in the field, he went to the M.I.T. Radiation Laboratory – then in the process of disbanding – and at Rabi's suggestion recruited Byron Havens, Robert M. Walker and John J. Lentz, who had been working in radar and advanced electronic circuitry and who welcomed a chance to apply their knowledge to computers.

Thomas J. Watson quickly gave the green light to construct the new machine in special quarters assigned to the purpose at Endicott and named Frank Hamilton as chief engineer. Eckert then delegated to Seeber, who had helped to program and operate the ASCC, the responsibility of providing liaison between the engineering and scientific groups during the design and construction of the machine.

Famed for the Thomas-Fermi-Dirac statistical theory of atoms and solids and for the theory of the spinning electron.



Eric Hankam, of the Watson Laboratory Staff, conducted many classes in computing. A total of 1600 people from 20 countries came for instruction.

[-17-]

Creating New Machines (1945-1954)

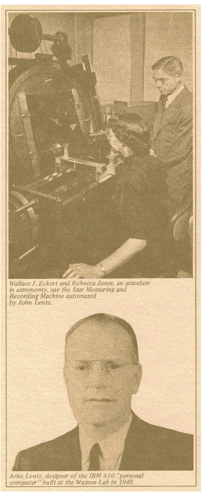
"The Interaction Was Very Close..."

By the end of November, 1945, the initial staff and equipment of the Watson Lab had moved into the renovated town house on 116th Street – a relatively small building with space for about two dozen people and a computer room. Through its portals, nevertheless, there flowed a steady stream of scientists and students from all over the world, technical people from other industries and from government agencies, IBM sales representatives and their customers, users of the Lab's comprehensive technical library and various other visitors. A prime attraction was the provision of free time on the Laboratory's machines to any scientist or scholar engaged in research, subject to the approval of a Laboratory consulting committee. The great majority of these researchers, working in physics, economics, crystallography, engineering, optics, astronomy and many other fields, had little or no experience with IBM machines or with the application of computational techniques to the [-18-] the country, relieving Watson Lab of the task in 1957. To acquaint scientists around the world with advanced, large-scale computing methods, the IBM Department of Education had previously begun the practice of holding annual Scientific Computation Forums. Through the technical papers which they contributed to these forums, Watson Lab staff members reached a large audience of scientists who were interested in computing.

The ferment that characterized the Lab in its first few years has been described by Eckert: "The interaction was very close... This was a very informal place. We felt that the people who were coming to solve problems should mix with the people who were learning and who were giving courses. We always had problems of our own, of course, that we were interested in getting solved. So the place was more like a university laboratory than a computing center. People sat around and discussed their problems and they would wait for the machines and while one person was using one machine, somebody else would be using another. So it was a very intimate arrangement."[9]

solution of problems. As a result, staff members in the early years of the Lab spent much of their time teaching people how to manipulate punch cards and get them through the machines. This effort was soon organized into group tutoring sessions – such as one in which a group of research geophysicists from the Lamont Geological Observatory at Palisades, New York, were intensively "prepped" for a week. In 1947, the famous "Watson Laboratory Three-Week Course on Computing", taught by Eric Hankam of the Laboratory staff, was started. It was subsequently attended by about 1,600 people from over 20 countries. The course was also offered to high school mathematics and science teachers and to high school students in the New York metropolitan area. So great was the demand for admittance to Hankam's course that IBM eventually created computer instruction centers at various locations throughout

The atmosphere was also highly conducive to creativity. Indeed, the many and varied research activities of the Watson Laboratory in the first few years of its life represented, in effect, the research effort of IBM itself during that time. Havens was at work on the design of an advanced, completely electronic machine with microsecond circuitry. At an early stage of this project, he designed a fundamental circuit – known in textbooks as the Havens microsecond delay circuit – that directly influenced the design of subsequent computers. The circuit took electric pulses that had been degraded by passage through many logic gates and reshaped and retimed them by separating them by one microsecond intervals. With this circuit, the entire central processor of a computer, containing thousands of components, could be kept



Top: Wallace J. Eckert and Rebecca Jones, an associate in astronomy, use the Star Measuring and Recording Machine automated by John Lentz.

Bottom: John Lentz, designer of the IBM 610 "personal computer" built at the Watson Lab in 1948.

[-19-] in synchronization, thereby providing highly reliable operation.

Concurrently, Lentz, who was interested in computer storage, was busy devising a one-tube storage element to replace the four-tube "flip-flops" then in use. The employment of vacuum tubes in computers was still relatively new and Lentz was experimenting with ways of using them to do arithmetic. While in the process of hooking together various pieces of equipment to test his new storage element, he realized that he could continue the process a few additional steps and create a small computer that could be operated by an individual sitting at a keyboard control. He went to work to construct such a machine, building the parts he needed – including a magnetic drum to supplement the more expensive vacuum tube storage – adding a paper tape punch reader and manual keyboard control. A feature of particular

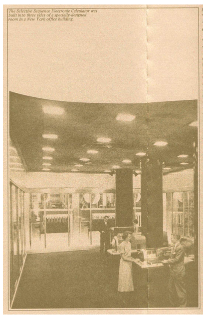
Project, for which the Laboratory provided the early asteroidal computations. To assist with this work, Lentz devised a machine that could scan a photographic plate of a portion of the sky that included a given star, read a punch card containing the star's approximate coordinates, use these coordinates to help locate the star on the plate, measure its position precisely and record the measurement on another punch card, making it available for subsequent mathematical treatment.

Walker, meantime, was also designing and building a machine at the laboratory in conjunction with Professor Francis J. Murray, of Columbia's Mathematics Department, who had proposed an improved algorithm for use in the solution of systems of simultaneous linear equations. The machine, the Linear Equation Solver, made possible the solution of up to twelve simultaneous equations. It employed static punch-card reading heads to read cards containing the matrix of interest: the calculator provided automatic positioning of the decimal point, making it one of the first machines to be built with this ability. The model, completed at the Watson Lab in 1948, became the prototype of the IBM 610 Autopoint Computer, which was placed in limited production in 1956. The eight year delay was caused by uncertainty as to the potential market for a small, portable "personal computer." Far ahead of its time conceptually, the 610 presaged "on-line" direct communication between individual and computer.

While working on the "personal computer," Lentz – in response to a request from Eckert – was also perfecting a Star Measuring and Recording Machine for use on astronomical photographs. In addition to his duties as director of the Lab and his teaching assignments at Columbia, Eckert had reactivated certain projects of the Thomas J. Watson Astronomical Bureau that had been set aside during the war. Among these projects were the Yale University Observatory's catalog of stars and the Yale Minor planet

coefficients of the system of equations to be solved. Trial values of the variables could be entered into the machine by adjustment of twelve input potentiometers. The accuracy of the provisional values was indicated by the reading on an "error" meter, which displayed the residual error of the solution. The machine demonstrated that the use of Professor Murray's algorithm resulted in the virtual elimination of interaction among the variable potentiometers and led to rapid convergence of the trial and error solution. The machine became a valuable addition to the basic equipment of the computational facilities of the Lab.

While working in computational theory and applied mathematics, Thomas and Grosch were also teaching courses to Columbia students. The announcement that instruction would be given in Watson Lab first appeared in a Columbia University bulletin of information for the winter session of 1946-47: "Members of the Laboratory staff offer courses of instruction in their fields of interest under the



The Selective Sequence Electronic Calculator was built into three sides of a specially-designed room in a New York office building.

[-20-] auspices of various departments of the University. Academic credit for these courses may be obtained by registering with the University in the usual manner and may be counted toward a University degree when approved by the department and the faculty concerned... Instruction in the Laboratory is designed for graduate students and research workers in science. It is contemplated that many of those taking this instruction will be candidates for advanced degrees in the various departments of science in Columbia and other universities, and the instruction offered by the Laboratory staff constitutes part of the regular offering of the different departments."[10]

Moreover, the architecture of the machine turned to advantage the difference in speed of the 13,000 fast vacuum tubes in the arithmetic unit, and the 21,000 relatively slower electromechanical relays elsewhere, by operating the relays and input tapes in parallel on eight separate channels. By programming the data to flow in parallel into the arithmetic units, it became possible to attack problems involving very long, tedious calculations.

Although he had originally been appointed by Eckert to perform only supervisory and liaison functions, Seeber became deeply involved with the actual design and construction of the SSEC. In the end, his contributions to the machine proved to be so important that he was

The facilities at the Lab also attracted scientists and scholars from research organizations all over the world. One of these was a young man named Frank Herman, who used the relatively primitive IBM Card Programmed Calculator at the Lab's computing center to make his well known computation of the band structures of germanium and diamond for his doctoral dissertation.* This work represented one of the earliest accurate computations of the energy levels of solids and constituted a breakthrough in the use of machine computation in solid state physics.

In some instances, staff members who were also teaching received appointments to the Columbia faculty. Thomas was appointed full professor of physics in 1946, and many other staff members held professorial appointments. The Lab, in its early years, initiated the practice of offering two annual fellowships in applied mathematics to Columbia graduate students, with winners selected by a faculty committee of the Mathematics Department. The first fellowships were granted in 1947-48, and a few years later the program was expanded to include support for graduate students, recommended by Columbia, who were seeking doctoral degrees from the university for work [-21-] performed at the Lab under the supervision of staff members.

The Selective Sequence Electronic Calculator

A project of highest priority at the Watson Lab in the late 1940's, of course, was the SSEC. Seeber, who moved up to Endicott in 1946 to work closely with the engineering staff, contributed some highly valuable ideas as to how the computer should be constructed. He proposed that "the instructions and the data be supplied in exactly the same format, and in this way it would be possible to take instructions through the computing element and modify them... particularly to modify addresses. Also I felt that this would be the basis of a branching operation which would be useful for such things as iteration."[11] This proposal amounted, essentially, to a primitive form of "stored program" – a concept that was to become of enormous importance in computer design.

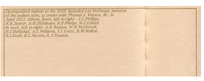
*Sixteen years later, Herman joined IBM and became manager of large-scale computation at the IBM Research Laboratory at San Jose, California.

named, with Hamilton, as co-inventor. In the meantime, Eckert had been thinking ahead to the selection of a problem of suitable complexity for the machine to demonstrate at the dedication ceremonies, which were to be very elaborate, with representatives of all the news media and of science, education, government and industry present for the occasion. He decided on the computation of the lunar ephemeris – the determination of the precise position of the moon – at intervals of twelve hours during the previous one hundred years and for the next one hundred years to come. For each position of the moon, the operations required for calculating and checking results totaled 11,000 additions and subtractions, 9,000 multiplications, and 2,000 table look-ups. Each equation to be solved required the evaluation of about 1,600 terms – altogether an impressive amount of arithmetic which the SSEC could polish off in seven minutes for the benefit of the spectators.

In the fall of 1946, Eckert assigned H.K. Clark, one of his associates at the Lab, to the task of writing the program for the lunar calculations under Seeber's direction. After the broad outlines of the program were developed by Eckert and by Rebecca Jones, an associate in astronomy, Clark wrote the actual step-by-step program, giving him claim to the title of first computer programmer at IBM.

Completed and tested in only eight months, the SSEC was moved in August, 1947 into a specially designed room in a building adjacent to IBM headquarters at 590 Madison Avenue in New York. The machine – the very model of what an "electronic brain" might be expected to look like – was built into three sides of a room 60 feet long and 20 feet wide so that visitors actually stood inside the computer. The rubber tile floor in geometric pattern, the silver and gold finished walls, recessed fluorescent lighting and black marble columns provided an impressive setting for the functioning sections of the computer. Behind glass panels set in aluminum frames, the memory units were stored; as they performed, small lights flickered and flashed like fireflies.

After rigorous testing, the SSEC was placed on trial operation in mid-December on the lunar ephemeris



Distinguished visitors to the SSEC included Lee DeForest, inventor

of the audion tube, at center with Thomas J. Watson, Sr., in April 1952. Others, font, left to right: J.C. Phillips, R.R. Seeber, A.H. Dickinson, B.E. Phelps, W.J. Eckert, In back, left to right: A.K. Watson, W.W. McDowell, H.J. Hallstead, A.L. Williams, J.J. Lentz, R.M. Walker, R.I. Roth, B.L. Havens. R.T. Paulsen.

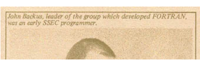
[-22-] program, which had been completed shortly before. At this point, Seeber and his group began to experience some of the troubles that sorely tried all operators of early computers. With alarming frequency, relays malfunctioned and vacuum tubes either failed or grew too weak to function. At the start of the day, the machine suffered from "morning sickness" and would not operate reliably. (This condition was eventually traced to the fact that the vacuum tube cathodes developed a coating overnight that interfered with their operation until they had been exercised.)

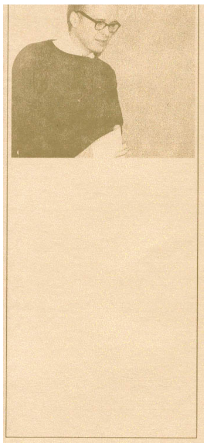
The day of the dedication, January 27, 1948, was described by Seeber as follows: "There was to be a luncheon on the second floor of the building... and all the prominent guests were to attend this luncheon. The machine had been working fairly well the day before, but that morning it began to develop a difficulty again, and on running the problem it would go to a certain point and then fail and stop. In order to restart, it was necessary to hand-position the tapes and start them over again... By lunchtime we still had the difficulty with us. Frank Hamilton and I had to go to the luncheon... the people downstairs... were trying to find some means of correcting the problem but finally... the assembled guests were coming down the stairway. So they felt, well, this is life... there was nothing more they could do about it. They started [the tapes] over again and the computer ran all afternoon."[12]

In the dedication ceremonies that followed – during which the SSEC performed flawlessly, grinding out several dozen good positions of the moon – Thomas J. Watson told 200 guests: "It is with a mixed feeling of humility and confidence in the future... that I dedicate the IBM Selective Sequence Electronic Calculator to the use of science throughout the world." The event – unlike the initial announcement of the establishment of the laboratory – was given [-23-] extensive coverage by the news media including a couple of newspapers that did not fail to wonder editorially why the new "robot brain" should not be given the job of figuring out income tax returns. Lunar coordinates obtained by the SSEC in the demonstration problem were useful to Eckert as checkpoints for his subsequent "Improved Lunar Ephemeris", produced in 1949, which gave the positions of the moon for the entire period 1952-1971. This became the standard ephemeris used the world over by astronomers. Fifteen years later, "The Ephemeris" and subsequent results which appeared under the titles "The Transformations of the Lunar Coordinates and Parameters," and "The Solution of the Main Problem of the Lunar Theory by the Method of Airy" were to constitute the basis for the orbital calculations of the NASA moon programs: Surveyor, Lunar Orbiter and Apollo.

Soon after the dedication of the SSEC, the company decided that the machine should be given a task more closely related to current developments – such as atomic physics, then much in the news – and a problem prepared by Thomas on the statistical distribution of electrons was chosen. The calculations, done by iteration, used continually revised sets of boundary conditions which Thomas worked out on a desk calculator. To indicate when computations with one set of boundary conditions were complete and another set needed, the SSEC programmers wired into the program the instruction "See Thomas." This procedure, which kept Thomas tied to the desk calculator, was superseded when the programmers obtained from him his method of obtaining boundary conditions and wrote a program sequence for the machine to do the same thing.

During the next four years, the SSEC worked on over thirty scientific problems submitted by industry, government agencies, and universities. For some of this work a fee was charged; in other





John Backus, leader of the group which developed FORTRAN, was an early SSEC programmer.

[-24-] instances, the return to IBM was in terms of experience in adapting complex problems to computer methods. The largest of these problems – perhaps the largest ever attempted anywhere up to that time – was "Hippo," a classified project for the Los Alamos Laboratory of the Atomic Energy Commission. Another, brought in by John von Neumann, involved equations needed to calculate viscous flow between two parallel planes. A problem sponsored by Eckert, and done in collaboration with Brouwer of the Yale University Observatory and Clemence of the United States Naval Observatory, required the computation of precise orbits for the five outer planets at intervals of forty days from the year 1653 to the year 2060. To help with the programming of such problems, a larger staff was clearly needed and Seeber brought in a number of mathematicians and other specialists during the next few years, including John Backus, William McClelland, Donald Quarles, Elizabeth Stewart, Joachim Jeenel, Harlan Herrick, Ruth Mayer Cornish, Frank Beckman, Hollis Kinslow, Phyllis Brown, Aetna Womble Dowst, Sherwood Skillman, Edward Codd and Janice Daly.

Despite its capabilities, the SSEC – built in the transition period between electromechanical and electronic machines, and suffering from reliability problems – soon fell victim to obsolescence, and in July 1952 it was dismantled. The machine nevertheless had a significant impact on all who had been involved with its career. Hamilton and other engineers who built the machine carried over their expertise to subsequent work on the IBM 650 computer, announced in 1953, which became one of the company's most popular machines. The programming group scattered to other areas of the company, where their experience proved very valuable. Jeenel joined Havens's project in advanced computer design. Backus, Herrick, Beckman, Quarles and Ruth Cornish joined John [-25-] Sheldon, who came from the Watson Lab to operate a new Scientific Computing Center – the company's headquarters office – and to work on programming for the Model 701. Later, Backus and Herrick transferred to the IBM Applied Science Department, headed by Cuthbert Hurd, and subsequently went on to create the computer programming language known as FORTRAN (Formula Translation).*

Perhaps the most important effect of the SSEC was on IBM management. Thomas J. Watson and other executives tended to view the powerful machine in somewhat the same manner as they had the Test Scoring Machine and the "Columbia Machine" – that is, as a boon to science and education.

Other members of management, including Thomas J. Watson, Jr., foresaw that industry, too, would soon be demanding electronic machines more advanced than even the SSEC. The younger Watson has described the situation at the time. "After the start of the Korean crisis, greatly increased defense activity in the aircraft, the atomic energy and the munitions manufacturing fields increased the demands for machines capable of engineering computations of the highest order. IBM was anxious to contribute in any way it could to the defense effort. Our electronic research had expanded greatly after the war, and by 1950 our people felt they had components which, if put together, could make the very large capacity tool that industry wanted. We developed a paper plan and decided perhaps we could get interested people to indicate to us that they wanted such a machine. Our engineers made a trip to the West Coast and came back with tentative orders for 18."[13] Since this was a far larger number than even the most optimistic predictions, IBM made the decision to enter the computer business. In the early 1950's, developmental work began at Poughkeepsie on the 701 Defense Calculator – the first production-line

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* For his role in this work, Backus was named an IBM Fellow in 1963.

located at

[-26-]

Top: Byron L. Havens, designer of the NORC.

Bottom: The Naval Ordnance Research Calculator built at Watson Lab was the most powerful computer in the world for nearly a decade. Faith Lillibridge is at the console.

computer specifically designed for scientific calculations – patterned on a machine designed at the Institute for Advanced Study by John von Neumann, Herman Goldstine* and Arthur Burks. Directed jointly by J. A. Haddad and Nathaniel Rochester, the 701 engineering program included use of the Havens microsecond delay circuit in key units and certain other technical developments initiated by Havens and his group at Watson Laboratory. Late in 1952, the first 701 off the production line at Poughkeepsie was installed in the show-case offices vacated by the SSEC next to IBM headquarters. It was less than a quarter the size of the SSEC and twenty-five times as powerful.

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* Now an IBM Fellow

The Naval Ordnance Research Calculator

The NORC's computing speed of 15,000 complete operations a second†, which exceeded its design specifications, was made possible by an arithmetic unit with addition time of 15 microseconds and multiplication time of 31 microseconds. The multiplier was of special interest and is described by Eckert in a book about the NORC. "There is a special product generator in the machine so constructed that, when a multiplicand flows into it, the nine multiples (from one to nine) of the multiplicand flow out of the other end... In hand multiplication we wait until all the multiples are completed before adding up the digits in the columns. The machine does not wait, but starts the addition immediately. This is accomplished with the aid of adding boxes so arranged that the sum starts flowing out immediately. This sum, which is the required product, flows into the registers until the complete product has been formed."‡

By 1950, Havens's plans for an advanced electronic computer had developed to the point where construction of a machine had become feasible. His "design objectives," in his own words, "were simple and straightforward... to build the most powerful and effective calculator which the state of the art would permit."[14] A customer for such a machine was found in the U.S. Navy's Bureau of Ordnance, which had been experiencing a growing need for a calculator to solve problems for which existing machines were too slow. McPherson – now an IBM vice president – brought representatives of the Bureau to the Watson Lab to review Havens's work, and when they expressed interest, a committee consisting of representatives of the Navy, Havens, McPherson and Eckert was formed to explore the Navy's requirements in greater detail. Before the end of the year, the decision was made for IBM to build the NORC (Naval Ordnance Research Calculator on a non-profit basis and with close consultation with the Bureau of Ordnance. Von Neumann was asked to serve as consultant on the project. Late in 1953, assembly of the machine was begun on the fifth floor of the Watson Lab.

[-27-] The NORC was not only the most powerful computer in the world – a distinction it held for nearly a decade – but it had certain features that were unique. Its 200,000 electronic components (vacuum tubes, resistors, crystal rectifiers, capacitors, inductors and pulse transformers) operated at one microsecond intervals – a speed achieved by the extensive use throughout of the Havens delay circuit, which made possible its complex logical organization. Storage in the NORC was of two kinds. Random-access storage of 3,600 words was provided by 264 Williams-type cathode-ray tubes timed to store, recover or refresh a word in 8 microseconds.* Main memory was provided by eight magnetic tape units, with four channels on each tape, that brought data into the machine at 70,000 decimal digits per second – more than five times faster than the fastest tape drives at the time. These tapes had been built to Havens's specifications by Ralph Palmer** and an engineering group in Poughkeepsie.

*Later the Navy replaced the cathode ray tubes with magnetic core storage.

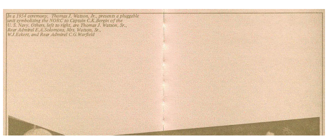
** Who later became an IBM Vice President and Fellow.

The NORC's reliability was no less impressive than its physical prowess. Exclusive of planned downtime for maintenance, the machine ran 92% of the system time available and operated an average of 700 hours a month. Unlike most computers, which perform calculations in binary notation – converting decimal input into binary before the calculations are made, then back into decimal afterward – the NORC employed decimal notation and operation in order to make programming easier. Each word of both data and instruction was composed of 16 decimal digits plus a check digit, making it possible to detect errors in word transmission, reading, recording and storing. This checking system was also used to run diagnostic test routines to prevent trouble in advance. Arithmetical calculations were checked by a process known as "casting out nines." Furthermore, the NORC was put together in removable basic sections – tape drives, cathode ray tube packages, multiplier unit, etc. – with stand-by parts for each section. When one part malfunctioned or began to give marginal results, it could be unplugged and replaced by a good unit. The faulty unit would then be plugged into a special dynamic testing machine to diagnose the trouble so that it could be repaired. This maintenance system was something brand new in computers and was regarded by some engineers as unnecessary and costly. The Navy, however, which had pressed hard for maximum reliability throughout the entire construction period, was thoroughly pleased with it.

The circumstances surrounding the NORC project were almost as unusual as the machine. Perhaps no computer was ever built with so much attention to the convenience of the user in terms of ease of operation, simplicity of programming and, above all, reliability. Many people worked with Havens to achieve these results. W.J. Deerhake, assistant manager of the project and responsible for the NORC's storage, devised special

† Each operation involved several steps: obtaining numbers from input or storage. performing the calculation, placing the decimal point, checking results, and returning to storage.

‡ *Faster Faster*, W. J. Eckert and Rebecca Jones, International Business Machines Corporation, 1955, pp.31-32.



In a 1954 ceremony, Thomas J. Watson, Jr., presents a pluggable

unit symbolizing the NORC to Captain C.K. Bergin of the U.S. Navy. Others, left to right, are Thomas J. Watson, Sr., Rear Admiral E.A. Solomons, Mrs. Watson, Sr., W.J. Eckert, and Rear Admiral C.G. Warfield.

[-28-] deflecting circuitry to overcome a difficulty arising from repeated reference to certain locations of data on the tube faces. Such a difficulty would ordinarily have had to be handled by complicated programming routines. K.E. Schreiner, who designed the machine's logic and controls, and C.R. Borders, who implemented the circuitry, were able to use the Havens delay circuits extensively to achieve synchronization of the complex organization of the machine. Robert Schubert, responsible for the mechanical design, worked to simplify the number of different types of packages involved. Joachim Jeenel, who had helped to write programs for the SSEC, was assigned by Eckert to head the programming organization for the NORC and to work closely with the designers of the machine in order to represent the interests of future programmers.

The NORC was a "custom-built" machine in a very real sense. A staff of nearly 60 people was required to assemble it from parts manufactured by IBM and by various small subcontractors in the New York area, including one in Paterson, N.J. who employed housewives, part time, to do hand wiring. To accommodate all this activity, the NORC group took extra space in a building at 2929 Broadway, near the Laboratory. Jeenel describes the setting: "It was a floor or so above some restaurant... and there was a group of maybe eight or twelve engineers just working away in this kind of office space, if you will." The sub-assemblies were then moved to the fifth floor of the Watson Lab. "At the end of two years or so, all of a sudden you have this great big wonderful machine. It was physically big, for one thing, and it was always a mystery to me how a thing like this could be created in these strange environments."[15]

The NORC was completed late in 1954 and officially delivered to the Navy in the presence of 200 scientific, business and military leaders at the Watson Lab on December 2, 1954. During the [-29-] ceremonies, IBM President Thomas J. Watson, Jr., presented one of the machine's pluggable units, symbolizing the calculator, to a representative of the Navy Bureau of Ordnance. The demonstration problem was the calculation of pi, computed to over 3,000 places. Guest speaker for the occasion was John von Neumann, who concluded his address: "In planning new computing machines, in fact, in planning anything new, in trying to enlarge the number of parameters with which one can work, it is customary and very proper to consider what the demand is, what the price is, whether it will be more profitable to do it in a bold way or in a cautious way, and so on. This type of consideration is certainly necessary. Things would very quickly go to pieces if these rules were not observed in 99 cases out of 100. It is very important, however, that there should be one case in a hundred where it is done differently... that is, to do sometimes what the U.S. Navy did in this case, and what IBM did in this case: to write specifications simply calling for the most advanced machine which is possible in the present state of the art. I hope that this will be done again soon and that it will never be forgotten."

Although the NORC was a cost-no-object, one-of-a-kind machine, and outside the mainstream of computer development, its influence on other computers was felt for many years. While it was under construction, engineers building the 701 not only made use of the microsecond delay circuit but also benefitted from Deerhake's work in overcoming difficulties encountered in electrostatic storage – which the 701 also used. However, the NORC's greatest contribution lay in the invaluable experience it provided scientists and engineers in computer design, construction and programming. Delivered to the Naval Proving Ground at Dahlgren, Virginia, in the summer of 1955, the NORC enjoyed a long, productive life until it was retired from service in 1968.

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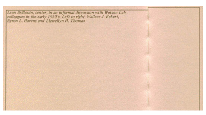

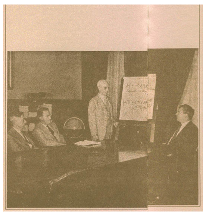

Leon Brillouin, center, in an informal discussion with Watson Lab colleagues in the early 1950s. Left to right, Wallace J. Eckert, Byron L Havens and LLewellyn H. Thomas.

[-31-]

Mission II (1952-1970)

Solid State Physics and Advanced Electronics

The development of the transistor was announced in the summer 1948, and the reverberations were felt around the world of electronics. Before the end of the year, the Poughkeepsie Laboratory of IBM had launched a study of the basic principles of transistor action to determine the feasibility of using the new devices as computer components. By the early 1950's, it had become clear that a broad basic research effort in solid state physics within IBM was required if the company was to keep pace with the fast moving developments in the field. During the next few years, this effort accelerated along several different fronts. At the Poughkeepsie Laboratory, under the management of Ralph Palmer, a staff of 50 scientists and skilled technical personnel was recruited to undertake research not only in transistors but also in semiconductors, ferroelectrics, magnetism, magnetic devices and other broad areas of interest to the company. In 1954, these activities were brought together in a new research facility in Poughkeepsie and soon after, a separate research organization was set up within the company's Research and Engineering Department there. At San Jose, an engineering laboratory which had been established in 1952 under Reynold Johnson to develop the [-32-] RAMAC (random access method of accounting and control) computer, expanded its mission to include research in magnetic recording, organic chemistry and electron beam physics. A new research laboratory, set up in Zurich, Switzerland in 1955, undertook basic scientific studies in such fields as magnetic thin films, fluid flow characteristics and superconductivity.

Columbia Physics Department, set about to recruit promising Ph.D.'s who could literally be turned loose, without senior direction, to examine various areas of the newly evolving discipline of solid state physics and to decide which ones – if any – they wished to explore. Since most of these areas represented foreign territory to students of physics at the time, Eckert looked for Ph.D.'s who had already demonstrated outstanding ability and who appeared to possess the imagination, enterprise and judgement to make the most of the practically unlimited freedom he intended to grant them. In adopting this approach, Eckert was acting in accordance with the well-documented observation that major advances are often achieved, not by working directly on immediate problems, but by almost unexpected developments in apparently unrelated areas. In his search for talented young scientists, Eckert had the counsel of the widely known physicist and mathematician Leon Brillouin, who had recently come to the Lab from Poughkeepsie, where he had been director of engineering education, to carry on pure research and serve as recruiting consultant. Before join-IBM in 1949, Brillouin had been Gordon McKay Professor of Applied Mathematics at Harvard University. A brilliant theorist with the ability to apply theory to practical engineering problem, Brillouin had made important contributions, not only to solid state physics and information theory, but also to the engineering of radio antennas, electric wave transmission in cables, and the motion of electron beams in magnetrons and travelling-wave tubes. Famous for his development of the theory of "Brillouin zones," he was also one of the first to apply Shannon's information theory to physics – work which he continued at Watson Lab.

The first two recruits, who arrived at the Lab fresh from earning their doctorates at Columbia in the spring of 1952, were Seymour Koenig and Sol Triebwasser. Koenig had done his thesis work with Professor Kusch as part of a series of experiments that was to be the basis for

Meanwhile, at Watson Lab in 1952, Eckert had requested and obtained approval from both Columbia and the company to expand the facilities and personnel of Watson Laboratory and, in cooperation with the Columbia physics Department, to establish a solid state physics program, including opportunities for graduate students at the University to do their thesis work at the Lab. Since this new mission was to be added to the Lab's on-going program in advanced calculating machines, additional space was clearly needed. A second, larger building – a former women's residence club at 612 West 115 St. – was bought by IBM, renovated, equipped with physics laboratories, and donated to the University. Meantime, Eckert, with the help of Professors Kusch and Rabi of the Kusch's 1955 Nobel Prize. Similarly, Triebwasser had done his thesis work with Professor Willis Lamb in connection with certain experiments that led to Lamb's Nobel Prize the same year. Two other new Columbia Ph.D.'s, Gardiner L. Tucker, a student of Professor Rabi, and G.R. Gunther-Mohr, a student of Professor Charles H. Townes, joined soon after. By the end of 1952, Richard L. Garwin, a former pupil of Professor Enrico Fermi, had come to the Lab from the University of Chicago where he had been an assistant professor of nuclear physics, and Erwin L. Hahn had come from a physics instructorship at Stanford University with an established reputation

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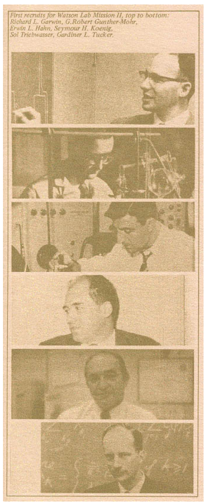

First recruits for Watson Lab Mission II, top to bottom:
Richard I. Garwin, G. Robert Gunther-Mohr,
Erwin L. Hahn, Seymour H. Koenig,
Sol Triebwasser, Gardiner L. Tucker.

in nuclear magnetic resonance. To this group Eckert soon added other scientists whose special training was needed to supplement the work of the original nucleus. Fred Holtzberg, a new Ph.D. from the Polytechnic Institute of Brooklyn with training in crystallography, was invited to join. Holtzberg subsequently brought in Arnold Reisman, a physical chemist, who later received his doctoral degree from the Institute. In the summer of 1953, Peter Price, a theoretical physicist with a doctorate from the University of Cambridge, came to the Lab from the Institute for Advanced Study at Princeton. Previously, he had spent a year as a "post-doc" at Duke University, where he worked with Professor Fritz London.

Much of Eckert's success in attracting this talented group was due to his soft-sell approach. As one of them described it: "He communicated the idea that we would be more or less expected to work in areas that IBM would appreciate, but that we were of Eckert in the house on 115th St. Nonconformity was taken for granted, personal idiosyncracies accepted and practical jokes tolerated. (One staff member shortened the cords of some of the telephones to a length of six inches, then watched interestedly as his colleagues tried to lift the receivers.) Dress was informal, with beards and sport shirts passing unnoticed – although a barefoot graduate student was briefly admonished. Bridge and chess games enlivened the lunch hour, and tennis games on Columbia's nearby courts were easily arranged. Members played concert violin, wrote limericks, collected African and Indian art, and one played the bagpipes in a Broadway musical. Time clocks remained unpunched. Efforts to introduce their use by the senior staff were firmly rebuffed. One, member who worked nights and slept days was seldom seen at all; those wishing to communicate with him left notes on his desk.

Bureaucratic processes were mercifully few. To obtain a piece of equipment, a staff member simply picked up to use our own judgement as to what these specifically should be."[16] Another recalls, with reference to Eckert's invitation: "The idea seemed to be absolutely extraordinary – there was no other place I knew of where a Ph.D. could come straight out of his thesis program and find out just how capable he really was."[17]

By the summer of 1953, the Lab quarters on 116th St. – already crowded with senior staff members working in electronics – were filled to overflowing, and additional space was found for the newcomers in an unused corner of the sixth floor of Pupin Hall, where it was so hot that shirtless physicists were a common sight. At one point, a single office was shared by Tucker, Triebwasser, Koenig and Gunther-Mohr. Without adequate laboratory facilities to work in, the recruits applied themselves to reading and planning. By the time the move was made to the building on 115th St. in September 1953, most of the group had staked out [-34-] the areas of research that they intended to explore. Eckert remained purposely aloof from these decisions; each man had been given a chance to prove himself and the rest was up to him.

Before tracing the subsequent careers and contributions of the group, it is illuminating to consider the fact – attested to by Lab alumni – that many of the individuals involved would not have joined the company except as members of the Watson Laboratory. The reason is to be found in the way of life which prevailed there, and which thus merits special attention.

A Way of Life

In somewhat the fashion of a large, diverse household presided over by a detached but protective parent, the scientists, office workers, engineers, technicians, service personnel, inventors and graduate students of the Watson Lab coexisted, in reasonable harmony, under the direction the phone and arranged to have it purchased – a fact recalled with nostalgia by virtually every alumnus of the Watson Lab. Organizational procedures that were closely observed elsewhere in the company – employee orientation sessions, detailed progress reports, formal relationships between employee and manager – proved curiously inapplicable in the climate of the Watson Lab. Most staff members reported directly to Eckert, who reported occasionally to McPherson at corporate headquarters. The relationship with Columbia was similarly free of constraints. There was a Committee on Cooperation between the University and the Lab, but it rarely met. Eckert explains: "Our agreements with the university were exceedingly informal. The best way to describe it is that we were invited to the campus to operate a laboratory with the understanding that if we didn't like being here or they didn't like us to be here the situation could be terminated... we never had detailed agreements about who would provide what or who was to do what."[18]

The sense of freedom engendered by the atmosphere at the Watson Lab created a euphoria among staff members that was to last, in most cases, for their entire periods of service there. Years after, they wistfully recall "the many good times and many scientifically stimulating times during those years;" "the unconventional atmosphere and the wonderful people;" "the easy on-campus way of life... I even used to audit anthropology classes;" "it seemed to us the best of all possible worlds."

The Work in Solid State Physics

The activities of the Watson Laboratory in solid state physics and advanced electronics in the 1950's and 1960's covered a broad research spectrum and greatly enhanced IBM's stature in the scientific community. Some of this re- search was carried out by scientists of

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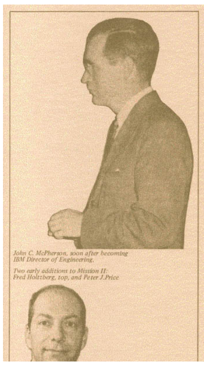

Top: John C. McPherson, soon after becoming IBM Director of Engineering.

Bottom: Two early additions to Mission II: Fred Holtzberg, top, and Peter J. Price.

different disciplines, or by scientists and engineers, working closely together. However, for the most part, the reputation of the Lab was built on the individual reputations of staff members who distinguished themselves in various areas of electronics and solid state physics. Of the original group who chose to work in solid state physics at the Watson Lab in the early 1950's – in the order of their joining the staff – Koenig concentrated on a broad program of semiconductor research. From 1953 to 1960, he studied the mechanisms of the low temperature breakdown of germanium. Between 1958 and 1963, he also investigated the general mechanisms of conduction in semiconductors, including degenerate semiconductors – primarily by hydrostatic pressure and uniaxial stress. By about 1958, Koenig became interested in semimetals, particularly bismuth. With the help of several students, he clarified the band structure of bismuth, explored the shape of the Fermi surface in detail, and made an intensive study of the electrical transport mechanisms.*

In 1959, Koenig and scientists at the Los Alamos Scientific Laboratory in New Mexico initiated a program in inelastic neutron scattering to determine the phonon spectra of various materials. The initial studies – only recently completed – were on bismuth. They were later extended to germanium and aluminum and led to a paper on sodium which was the first to show, unequivocally, the oscillation in the sign of the ion-ion interaction commonly known as the "Friedel wiggles." In 1964, this work was extended to the study of the structure of liquids, particularly liquid argon. The experience gained from these experiments was transferred to analogous ones (now in progress) in which laser radiation is substituted for neutron radiation and protein solutions for argon. Triebwasser became interested in the relationship between the microscopic and thermodynamic properties of [-36-] ferroelectric crystals. He made extensive use of Lentz's "personal computer" to calculate the internal fields and Lorenz factors in perovskite structures and relate them to the thermodynamic free energy. Much of his work was initiated in barium titanate and subsequently extended to solid solutions of the potassium-niobate-tantalate system. For the latter work, he collaborated with Holtzberg and Reisman in a comprehensive study of the chemistry and crystal growth of this system.

Tucker elected to work in semiconductor research. At the suggestion of Price, they looked for and found an electric breakdown in semiconductors at liquid helium temperatures. Shortly after joining the Lab, Tucker left to become manager of semiconductor research at the Poughkeepsie Laboratory.

Gunther-Mohr, who had also chosen to work in semiconductors, collaborated with Koenig in the initial phase of systematic, comprehensive studies of the low temperature breakdown of germanium. In addition, he specialized in the atomic properties of the crystal lattice, and initiated a precision experiment to measure the self-diffusion of germanium using radioactive tracers. In 1957, he succeeded Tucker as manager of semiconductor research at Poughkeepsie. His diffusion studies were then carried on by an associate, Hans Widmer, who used them as the basis for a Ph.D. thesis submitted to the Swiss Federal Institute of Technology. Widmer continued his work with Arthur S. Nowick, who came to the Lab in 1957 from an associate professorship in metallurgy at Yale University.

Garwin's scientific interests covered so many areas of physics, to which he made so many contributions, that he has been characterized by associates as "a national resource." His initial research in liquid helium was followed by investigations of superconductivity. He made an early analysis of the potential of the cryotron, which had recently been developed at Massachusetts Institute of Technology,

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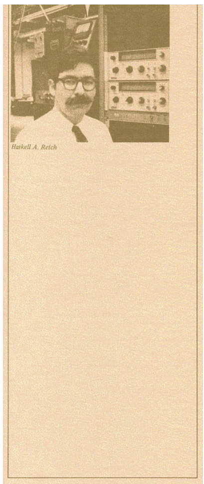
*Aware of the growing interest in semimetals. Koenig and Price in 1964 organized a conference at Columbia on the physics of semimetals. sponsored by the Watson Lab and the American Physical Society. The proceedings of the conference were reprinted in the July 1963 issue of the IBM Journal of Research and Development.



Haskell A. Reich

and laid the foundations for "Project Lightning," an IBM Research program (partially sponsored by the Government) to develop superconducting elements for computers. He studied the technology of cooling computers by the use of refrigerants and helped to build the first continuous helium-3 refrigeration system. He also contributed importantly to the work in magnetic memory and solid-state acoustic delay-lines, and designed various devices for research in nuclear and low-temperature physics. Subsequent experiments with thermal conduction and diffusion, and spin relaxation effects in both liquid and solid helium were carried out by Haskell A. Reich, who became an associate of Garwin upon receiving his Ph.D. from Columbia in 1955. As time went on, he was also to make important contributions to the cause of laboratory automation and terminal-oriented computing.

Garwin's best known scientific work was in the physics of elementary particles. An event of particular note in the history of the Watson Laboratory was the set of experiments on muon decay conducted in January 1957 by Garwin, in conjunction with Professor Leon Lederman of the Columbia Physics Department, in which the University's cyclotron was used to demonstrate the non-conservation of parity in weak interactions. These experiments confirmed the theoretical work of Professors C.N. Yang and T.D. Lee, establishing the basis of their Nobel Prize in 1957. In 1960, Garwin extended the techniques and experience gained from the Columbia experiments to another series of experiments conducted at the Geneva, Switzerland, headquarters of the European Organization for Nuclear Research (CERN). In these experiments, the anomalous magnetic moment of the mu meson was precisely measured; the result showed that the mu meson might be regarded simply as a heavy electron.

back in phase resulting in an echo. The technique was believed to have potential value for information storage purposes. Hahn concentrated on extending these techniques to both nuclear quadrupole resonance and double nuclear magnetic resonance in solids. In 1955, Hahn accepted an appointment as professor of physics at the University of California at Berkeley.

Soon after, Alfred G. Redfield joined the Lab from a research fellowship at Harvard University, where he had been carrying on fundamental research in the technique of nuclear magnetic resonance in solids. He continued his work at the Lab, concentrating on the properties of both normal and superconducting metals at very low temperatures. Recently, he succeeded in using these techniques to determine the form of the vortex state of Group II superconductors.

Holtzberg and Reisman undertook an intensive investigation of the chemistry of the reactions of alkali-metal carbonates with pentoxides of the Group VB elements, and pursued a broad study of the behavior of model compounds and the prediction of compound behavior. As part of these studies, crystals of compounds were prepared and their ferroelectric and other properties were investigated. In conjunction with Triebwasser, Holtzberg and Reisman also studied the chemistry and crystal growth of potassium niobate and tantalate.

Price's original interests had been in superfluidity and statistical physics. On arriving at the Lab, he decided to specialize also in semiconductor physics. After initiating the investigation of "hot electron" phenomena, he developed a kinetic theory of low temperature breakdown in semiconductors which was verified by the experiments of Koenig. Price continued for some years his work in superfluidity before concentrating on solid state physics exclusively. His work on hot electrons evolved into a broad program of work in the basic theory of electron transport phenomena, and its linear and non-linear applications. He also contributed to the

While pursuing his scientific work, [-38-] Garwin was also achieving national stature as a consultant to U.S. Government departments and agencies on such matters as the design of nuclear weapons, military technology and defense strategy, arms control and disarmament, and civilian problems of many kinds including housing, air traffic control and the supersonic transport plane. A member of the President's Science Advisory Committee from 1962 to 1966, he was reappointed in 1969.

Hahn's work at the Lab centered on the investigation of a phenomenon he had discovered called "Spin Echoes." This is a technique for studying nuclear magnetic resonance by using a transient – rather than steady-state – mode of operation. Pulses of high frequency radio waves are used to probe the nuclei of small samples of material in order to measure the magnetism created by the spinning of nuclei around their axes. A pulse causes the nuclear spins to start precessing in phase. When the spins soon get out of phase, another applied pulse brings about a phase reversal of precession. At a measurable time later, the spins get theory of nonlinear optical properties of solids, strain effects, fluctuations and electron tunneling in junctions.

Over the years, the staff of the Lab was augmented by the arrival of other scientists in various areas of specialization. Yasuo Sato, a geophysicist from the University of Tokyo, arrived in 1960 to undertake studies of the propagation of seismic disturbances in the earth's surface and numerical analysis of the seismograms of earthquakes. Martin Karplus, an associate professor of physical chemistry at the University of Illinois, also joined in 1960 to work on the application of computer calculation to theoretical chemistry. He and his associates developed a program to calculate cross sections for exchange reactions, a statistical averaging program, and a method of integrating Hamilton's equations. In addition,

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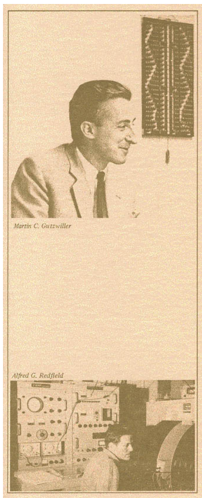

Top: Martin C. Gutzwiller.
Bottom: Alfred G. Redfield.

they worked out a way to make atomic calculations by the configuration-interaction technique in which the atomic wavefunction is written as an expansion of "configurations," each of which is an antisymmetrized set of products of one-electron orbitals occupied by the different electrons. In 1966, Karplus went to Harvard as professor of chemistry.

William J. Nicholson, a recent Ph.D. from the University of Washington, came to the Lab in 1960 and specialized initially in the application of the Mossbauer effect to problems in ferromagnetism. remained at Watson Lab, where he pursued independent research in atomic beam spectroscopy. He built apparatus to investigate atomic properties – principally fine and hyperfinestructure, nuclear moments, gyromagnetic ratios and optical transition lifetimes in Group 11 elements.

Time and frequency standards had been a continuing interest at Watson Lab from its inception. The orbit of the moon calculated by Eckert was useful to astronomers as a giant clock, and the cesium atomic beam was being tested at the Bureau of Standards and elsewhere as a standard of frequency. In line with these

Two years later, James L. Levine joined the staff and carried on experiments in superconductivity. By studying tunneling in junctions, he measured the lifetime of excitations in superconductors.

In 1963, M. C. Gutzwiller, a theoretical physicist, transferred from IBM's Zürich laboratory. His interest then was the theory of ferromagnetism, particularly the effect of correlation on the ferromagnetism of transition metals. He also investigated the quasiparticle spectrum in narrow bands, and electron states around a dislocation in a crystal lattice. More recently, a growing interest in the relationship between classical and quantum mechanics has led him to develop new methods of using classical mechanics to approximate the Schrödinger equation.

While much of the work in solid state physics at Watson Laboratory did not lead to specific development programs in the company, it added to the broad body of scientific knowledge in the field, helped to keep IBM alert to significant developments, and provided a basis for future technological decisions. Not surprisingly, there was a significant increase in the interaction with Columbia as the work in solid state physics progressed. Approximately 15% of the graduate students from the Physics Department in the 1950's and 1960's did their thesis work – [-40-] mostly in solid state physics – under Watson Lab auspices. Over the years, the availability of these graduate students served an important function at the Lab, making it feasible to launch pilot projects of various kinds and then continue or terminate them with a flexibility that would not have otherwise been possible.

Advanced Electronics

Paralleling the work of the solid state physicists in the 1950's and 1960's were the investigations by members of the original staff of the Lab into certain areas of advanced electronics. Havens, having completed the NORC, started out anew with a group of associates, including Schreiner, to adapt microwave circuits to computer logic in the form of a very fast adder. Three physicists – Allen Lurio, Arthur Nethercot and Thomas Morgan – also joined Havens's group. when the microwave effort moved to another IBM research facility a few years later. Lurio, who had been a physics instructor at Yale University, interests, Havens turned his attention to the gas maser, newly developed at Columbia University by by his former Caltech classmate Professor Charles H. Townes, because of the possibility of using it as a frequency standard. In 1958, Havens and an associate, John Cedarholm, worked with Townes at the Lab to perform a sophisticated version of the classical Michelson-Morley experiment of 1887. By comparing two ammonia masers, built and operated at Watson Lab, the experimenters reconfirmed the basic contention of Einstein's Special Theory of Relativity that the speed of light is independent of the velocity of its observers. The measurement was made to an accuracy of one part in 10^{12} – one of the most precise ever performed up to that time.*

The protean influence of Thomas continued to be felt – as it had from the Lab's first beginnings – on programs of many kinds, prompting Eckert to note in one of his reports on Watson Lab activities: "Perhaps there should be a box on the organizational chart labelled L.H. Thomas." One of Thomas's important contributions to theoretical physics, "The Calculation of Atomic Fields," was published in 1927 while he was still at Cambridge University. This work was refined in 1928 by Enrico Fermi, and in 1930 by P.A.M. Dirac, to produce what is widely known as the Thomas-Fermi-Dirac theory of the atom. In 1927, Thomas also published "The Kinematics of an Electron with an Axis," which physics students learn as the "Thomas factor" in atomic spectroscopy. As early as 1938, he showed that the energy limitations of a cyclotron can be overcome by strong focusing, and suggested new approaches to the construction and operation of the large machines that are now standard.

In applied mathematics, Thomas pioneered in the development of an iterative computer method of approximating wave functions for three-particle problems and in adapting for computer solution problems in hydrodynamics, elasticity theory and electron distribution in atoms. His suggestions for the NORC included three-way branch instruction and tape – rather than drum – storage. He also made important contributions to the work on microwaves, ultra-high frequencies, subharmonic resonance, negative resistance,

*The experiment was accorded front-page treatment in the *New York Times.*

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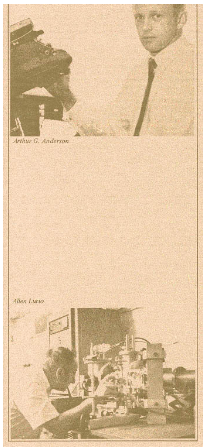

Top: Arthur G. Anderson.
Bottom: Allen Lurio.

and a variety of new storage devices. As far back as 1946, he had considered the possibility of using tiny pieces of various kinds of steels to store information magnetically and perform logic – work which anticipated the subsequent development of magnetic core memory. He was also considering the applicability of various kinds of delay line devices for information storage. One of his collaborators in this research for a time was Arthur G. Anderson, a young physicist who had transferred from the Poughkeepsie Laboratory in 1953 to pursue graduate studies in New York and who built one of Thomas's electromagnetic delay line devices. Anderson was soon given a second assignment in the area of storage: to assist on the "Spin Echoes" project. He thereby joined a whole group of staff members who, at one time or another, became associated with the project. One scientific paper, titled "Spin Echo Serial Storage" – published in the Journal of Applied Physics in November 1955 – bore the signatures of Anderson, Garwin, Hahn, Horton, Tucker and walker. (Not noted in the paper was the discovery by the authors that "Wildroot Cream Oil" hair tonic was a most satisfactory source of protons for information storage.)

Walker, meantime, had begun to explore the possibility of operating an arithmetic unit in the 50-megacycle range – a remote frontier area at the time. Assisting him were Anderson and Donald Rosenheim, a young IBM engineer who had also transferred from the Poughkeepsie laboratory to do graduate work. Subsequently, P. A. Lewis, a Columbia graduate student, joined the group. The results of their work were published by the four authors in 1957.* During the investigation of the fast adder, Walker had become interested in the problem of the influence of various design and operating factors on computer reliability, about which little was understood at the time. He undertook a project to quantify reliability theory, and with [-42-] Rosenheim and Lewis, made an

An excellent opportunity in this line arose in 1955, when Tucker was named a member of a task force to study the future of research at IBM and make recommendations in that regard. One result of the study was a decision by the company to establish a much more broadly based research organization. In 1956, it was announced that Watson Laboratory and the three other research laboratories at Poughkeepsie, San Jose, and Zürich would be administratively combined into a corporate IBM research organization with headquarters at a new building to be constructed in New York's Westchester County. Meantime, a new laboratory was built at Mohansic (also in Westchester) in 1956 to house research and development activities. The same year, Emanuel R. Piore, who had been vice-president for research and director of Avco Corporation and, earlier, Chief Scientist of the Office of Naval Research, joined IBM to build up the company's research program. In 1957, Piore appointed Tucker to a 3-man IBM Research Analysis and Planning Staff-known generally as the "Three Wise Men" – to help make plans for the new organization.*

As the Thomas J. Watson Research Center neared completion at Yorktown Heights, N.Y. in late 1960, new facilities became available where basic research could be carried on. This prospect – together with the coordination of the activities of the various outlying laboratories – provided Watson Lab staff members with opportunities to move out to locations where their various kinds of expertise were relevant and where there was room for projects to grow. During the late 1950's and ear1y 1960's, there was a broad exodus of Lab staff members into IBM scientific and engineering management at many levels. Walker joined the San Jose laboratory as manager of the communications science department. Havens became resident manager of the Mohansic laboratory, served as director of product and development engineering for World Trade Corporation, and subsequently became vice president in charge of the European laboratories of the Systems Development Division. Gunther-Mohr, who had become manager of semiconductor research at Poughkeepsie, went to analysis of field data for use in the development of reliability prediction theory. Betty Flehinger, a research assistant in Columbia's Mathematics Department, joined the Lab in 1959 to work on the problem. This project marked the beginning of IBM's subsequent extensive program in the area of computer reliability theory. Some of the redundancy techniques that were later employed – for example, in the Federal Systems Division's Orbiting Astronomical observatory – arose from the reliability studies initiated at Watson Lab.

The Expanding Role of Research

Shortly after joining the Lab in 1952, G. L. Tucker had become interested in research management. Eckert recalls: "Unlike many research managers who are primarily interested in their own research project, he decided while at the Watson Laboratory that management was his chief interest and set that as his goal."

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*"An Experimental 50-Megacycle Arithmetic Unit," *IBM journal of Research and Development*, Vol, 1, No. 3. July 1957.

Yorktown as manager of applied physics and engineering; later he joined the Components Division, where he became assistant to the president. Price went to Poughkeepsie to help develop and lead the pure physics group in Gunther-Mohr's semiconductor department, then returned to Watson Lab. Rosenheim became manager of high speed circuits and systems at Yorktown and was subsequently appointed director of applied research. Triebwasser went from Watson Lab to Poughkeepsie as manager of ferroelectric research, then to Yorktown, where he subsequently became assistant director of applied research. Among other Watson Lab staff members who went to Yorktown were Holtzberg, Reisman, Lewis and Betty

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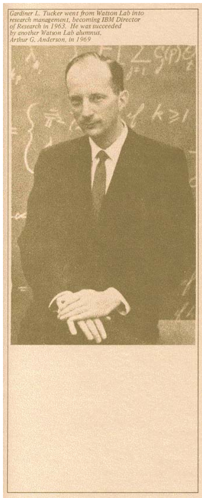
*The other two members of the group were M. Clayton Andrews and John Gibson.



Gardiner L. Tucker went from Watson Lab into research management, becoming IBM Director of Research in 1963. He was succeeded by another Watson Lab alumnus, Arthur G. Anderson, in 1969.

Flehinger. Garwin spent a year there as manager of applied research, then returned to Watson Lab to become its director in 1966. Nowick carried on his work in metallurgy at Yorktown until 1966, when he became professor of metallurgy at Columbia University. John Lentz went to Poughkeepsie; then to Yorktown to participate in the program in superconducting computers; returned to Watson another. At the same time, each member of the group was entirely self-contained and self-directed in his own area of expertise. As a result of this dualism, the atmosphere of the Lab was not only very stimulating and productive of new ideas, but – in the words of one staff member – "it was more interdisciplinary than a university..."[20].

Lab to work with Thomas on the design and construction of a special kind of cyclotron, then rejoined Yorktown where his experience in hardware and software, coupled with his broad background in both physics and engineering, are now being applied to complex problems involving remote entry to computers.

Gardiner Tucker, who had left Poughkeepsie to become manager of research at San Jose, went on to the World Trade Corporation as director of development engineering, then became IBM Director of Research in 1963. Four years later, he was invited to Washington to become Deputy Director, Defense Research and Engineering, in the Department of Defense. In 1969, he was named an Assistant Secretary of Defense. He was succeeded as IBM Director of Research by Arthur G. Anderson, who had gone from the Watson Lab to San Jose as manager of the San Jose laboratory, and then served under Tucker as assistant IBM Director of Research at Yorktown.

Summing up, Eckert has commented '...if you look over the scientific and engineering management of the company now, there are about fifty people... who are fairly well thought of and all started here. Our people have almost invariably made good elsewhere in the company... We have a very interesting group of alumni."[19]

Over the years, some who had been Watson Lab members went into new fields. H.R.J. Grosch, who left the Lab in 1950, held a number of industrial, academic and governmental posts, including [-44-] that of director of the National Bureau of Standards Center for Computer Science and Technology. John Sheldon founded Computer Usage Corporation. When Columbia established its own Computing Center late in 1962, the Watson Lab building on 116th St., which housed the computing machines, was closed;* Kenneth King, who had been manager of the Lab's computing facilities, went to the new Columbia installation to help it get started. He later became its director.

"More Interdisciplinary than a University"

Members took advantage of sabbaticals or summer vacations to pursue interests completely different from their usual ones. In addition, as Arthur G; Anderson has pointed out, "[a] characteristic of... small laboratories is that you find there a great deal of intermixing of skills. In general, people know and help everyone else... the morale and the identification with the laboratory can be very, very high; it is a much more personal environment. Therefore, I think generally you find the loyalty to the laboratory is very high, perhaps higher than in a bigger location."**

Among Watson Lab staff members who remained at the Lab and who held University appointments were Eckert, who taught astronomy for 23 years; Thomas†, who taught physics for 18 years; Garwin, who taught various aspects of physics over a period of 16 years; Redfield, who taught physics for 14 years; Koenig, who taught quantum mechanics and solid state physics for 11 years; Gutzwiller, who taught theory of metals for 7 years; and Lurio, who taught undergraduate physics for 5 years. A staff member could elect to teach, carry on his own research, undertake new projects, involving a few graduate students, that could be expanded or terminated easily. Given the catholic interests of the staff, this degree of freedom led quite naturally to the involvement of the Lab in a wide range of scientific, academic and governmental projects.

Garwin, for example, besides his major interests, explored such diverse areas as the manufacture of synthetic diamonds, the design of a solar energy converter, superconducting lines for the transmission of power over great distances, military technology, and the impact of information handling systems on health care. He also worked with the Physical Science Study Committee and took part in the Engineering Concepts Curriculum Project to improve and enrich high school science courses – a cause that was championed by many Lab staff members. Redfield, in addition to his work in NMR, became interested in superconductivity and the high temperature properties of crystals. He, too, joined with physicists at M.I.T., Cornell and the University of Illinois on the physical Science Study Committee to develop a high school physics program including textbooks, experiment manuals. and a movie dealing with the Millikan Oil Drop experiment. Nicholson worked with Educational Services, Inc. to

Other Lab staff members – notably Eckert, Thomas, Lurio, Garwin, Koenig, Price, Redfield and Gutzwiller – stayed at, or returned to, the building on the Columbia campus to continue their research and to teach. This group shared a broad range of scientific and other interests, keenly enjoyed interdisciplinary discussion and collaboration, and had the flexibility – to an extraordinary degree – to move easily from one scientific area to develop a mathematics curriculum for a program designed to improve the chances of poor, black students in getting into – and staying in – college.

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*With the removal of the computing machines. the name of the laboratory was changed to the IBM Watson Laboratory at Columbia University.

**"The Role of the Outlying Laboratories," presented at an Industrial Research Institute Symposium on Coordination of Research on a World wide Basis, Quebec, P.Q., Canada. October 10, 1967.

†Five years after he was named an IBM Fellow in 1963, Thomas retired. Subsequently, he became Professor of Physics and Mathematics at the State University of North Carolina in Raleigh.

[-45-]

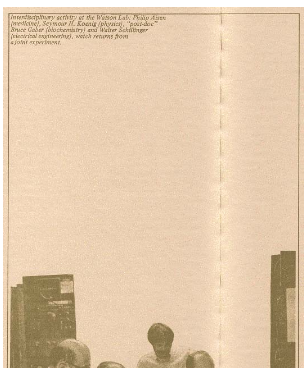
The light side of life at the Watson Lab, circa 1953: Donald Rosenheim, left, and Arthur G. Anderson, right, duck the unwary John Horton in a fountain on the Columbia campus.

This project eventually grew into the Upward Bound Program. Koenig went to the Zürich Lab in late 1961 to initiate a program in semiconductor research. On his return in 1962, he turned to a new area of interest. He undertook studies in the physics of proteins in order to discover "if an experimental physicist could contribute to the understanding of biological problems." He participated in the Cambridge Conference on School Mathematics in 1963, which made proposals for the revision of mathematics curricula for kindergarten through the 12th grade. Thomas, Garwin and Koenig all served as consultants to the Atomic Energy Commission's Los Alamos Scientific Laboratory for a number of years.

In large part because of these activities, Watson Lab staff members were widely known in the scientific community and successful in bringing highly qualified people into IBM. Among the outstanding scientists whose decisions to join the company were influenced by their acquaintance with, the work at the Watson Lab were J.B. Gunn, who subsequently discovered the "Gunn Effect", and Leo Esaki, inventor of the tunnel diode. Both Gunn and Esaki began their IBM careers at the

Efforts were also continued to recruit talented young graduate students, and by the early 1960's candidates were sought in the biological and medical sciences. Research in photosynthesis had been started at the Lab in 1961 by S.S. Brody, and there was a feeling on the part of Tucker and others in Research, including Koenig, that IBM should increase its exposure to various areas of life sciences. Elsewhere in the company, some foresaw that these areas might become of potential commercial importance to the company as computers came into greater use in medical research involving large quantities of data and in the automation of clinical laboratory procedures.

[-46-]



Poughkeepsie Laboratory, then moved on to Yorktown.

Interdisciplinary activity at the Watson Lab: Philip Aisen (medicine), Seymour H. Koenig (physics), "post-doc" Bruce Gaber (biochemistry) and Walter Schillinger (electrical engineering), watch returns from a joint experiment.

[-47-]

Mission III (1964-1970)

The Life Sciences

In 1964, a formal decision was made by Tucker to initiate a program in molecular biology and biochemistry at the Watson Laboratory. As in the case of the solid state physics program, scientists were recruited who had demonstrated outstanding ability in their respective areas. Among those who joined was Philip Aisen, an M.D. and biochemist from the Albert Einstein College of Medicine, who undertook the study of metal-bearing proteins found in the body in hope of understanding their biological functions. Aisen concentrated on the properties and behavior of transferrin, a plasma protein [-48-] which binds iron and carries it to immature red blood cells in the bone marrow to be incorporated into hemoglobin molecules. His two principal areas of interest were transferrin's iron-binding and release mechanism, and the means by which the protein confines its transfer function specifically to the immature blood cells. Aisen left Watson Lab in the summer of 1970 to become acting chairman of a newly formed biophysics department at Albert Einstein College of Medicine.

Thomas Fabry, a post-doctoral fellow in physical chemistry at Yale University, came to the Lab in 1965 to study the primary structure of proteins. His work soon led him into biochemistry, then biophysics, to pursue an interest in hemoglobin and the manner in which its function relates to its structure. Fabry focused on the iron-carrying heme group in the metal-protein complex and on closely allied substances in order to clarify the mechanism of the reversible binding of oxygen to hemoglobin.

by the use of electronic measuring devices which automatically punched their output on a 526 Card Punch. In 1966, while serving as assistant to G.L. Tucker at Yorktown, he became familiar with APL language, then being implemented for time-shared terminal use by K.E. Iverson and his associates, and with the M44/44X time-shared computer.

Making use of a data interface built for him by L. B. Kreighbaum, he devised one of the first on-line data reduction systems at IBM involving a time-shared machine. In the system, data from Reich's nuclear magnetic resonance experiments at Watson Lab were digitized by a digital voltmeter coupled to the interface unit, which then fed the digitized data to a 1050 terminal connected to the M44/44X in Yorktown. Upon command, the computer performed the calculations required by the experiments. Reich's success with this system stimulated others at the Lab, including Koenig, Aisen and Fabry, to utilize similar equipment and procedures. With the availability of the System 360/50, speaking APL, on-line computing soon spread to experiments throughout the Lab. Most recently, a dedicated 1130 computer was used at the Lab mainly to handle continuous averaging of transients in connection with high-resolution magnetic resonance experiments and an assortment of less demanding experiments carried on by Redfield.

Biomedical instrumentation became another area of interest at the Laboratory in the 1960's. In early 1964, Louis Kamentsky, who was then in the pattern-recognition group at Yorktown, was invited to Watson Lab to pursue the development of a device he had invented called a rapid cell spectrophotometer, or RCS. The RCS passed biological cells in liquid suspension under a microscope objective at the rate of a thousand

Koenig was also interested in the behavior of protein molecules, and he made use of various experimental tools to study the interaction of protein molecules with water. He extended the technique of nuclear magnetic relaxation dispersion to a broad range of diamagnetic and paramagnetic proteins to examine the effect of dissolved proteins on the spin-lattice relaxation time of solvent water protons.

Ever since Haskell Reich's early work in accumulating large bodies of data in the late 1950's, the cause of automation had been of prime interest at Watson Lab. In 1965, Reich built a machine to replace the reading of 10,000 oscilloscope photographs per second and recorded several optical parameters for each cell. The purpose of the device was to detect the presence of cancer cells, which metabolize more rapidly than normal cells, and should therefore have greater optical absorption than normal cells in the ultraviolet portion of the spectrum where nucleic acids absorb light. The hope was to automate cytological procedures for the Papanicolaou test. The initial trials were sufficient1y promising so that Koenig organized a double-blind test of an automated version of the machine – designed and built by

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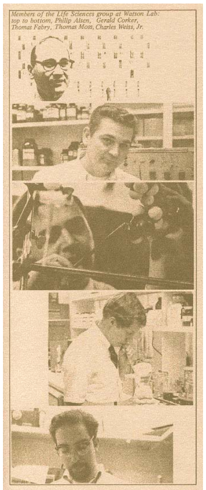

Members of the Life Sciences group at Watson Lab: top to bottom, Philip Aisen, Gerald Corker, Thomas Fabry, Thomas Moss, Charles Weiss, Jr.

Rodney Brown – which involved the cooperation of Metropolitan Hospital and Memorial Hospital for Cancer and Allied Diseases in New York City.* The results of the test, since published, showed that the machine could triple the throughput of a cytological laboratory if used for prescreening "Pap" smears. Kamentsky, meanwhile, went on to develop methods for interfacing the RCS to a computer. He subsequently left IBM to form a company to exploit the clinical applications of the device. In 1966, Regina O'Brien, a histochemist and assistant professor of biology at New York University, was recruited by Watson Lab to study other biological applications of the RCS. In the area of automated medical screening programs, the Lab supported a program in conjunction with the Albert Einstein College of Medicine, in which John Lentz participated, to automate large-scale screening of blood constituents as a means of identifying genetic abnormalities by pinpointing anomalies in blood chemistry which might result from deviant gene activities.

[-50-] The Life Sciences group, in addition to their scientific investigations, also took part in curriculum reform. Aisen worked with a colleague at M.I.T. to prepare a two-year college physics course, with problems based on physiology and medicine, for a projected Harvard-M.I.T. School of Health Sciences and Technology. Moss, who worked with the Urban League Street Academy program to interest ghetto children in science, arranged for some youngsters to work at the Lab and visit the operations at Yorktown.

Toward "Watson Laboratory: Phase II"

In 1966, obeying a long-felt desire to return to full-time astronomical research and teaching, Eckert stepped down as director of the Lab and was succeeded by Garwin, who had been associate director from 1960 to 1964. The following year Garwin and Eckert were named IBM Fellows. Eckert's citation read: "As teacher, author, scientist and laboratory director, Dr. Eckert has been a leader in the application of calculating machines to scientific computations." Concerning Garwin: "He

Thomas Moss, a Cornell Ph.D. in biophysics, joined the Lab in 1967 to pursue his interest in the structure of metal proteins involved in electron transport both in metabolism and in photosynthesis. Also concerned with problems in photosynthesis were W.J. Nicholson, who joined the work in biophysics in the early 1960's; Gerald Corker, a new Ph.D. from the University of California; and Charles Weiss, Jr., a Harvard Ph.D. In 1968, Nicholson left the Lab to become associate professor of biophysics at the Mount Sinai Medical School. The chief aspect of photosynthesis under study at the Lab was the initial phase – the primary quantum conversion reaction. In this phase, photosynthesizing organisms, when exposed to light, produce free radicals and exhibit changes in optical absorption spectra. The technique of electron spin resonance was used to study the light-induced free radicals in both whole cells and particulate samples.

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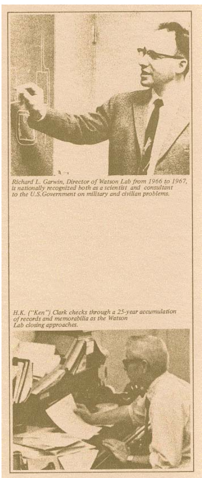
*From 1965 to 1968, Kamentsky undertook further engineering development of a prototype machine with the assistance of Central Scientific Services at Yorktown.

has made major contributions to the study of contemporary physics and has devoted substantial time at the policy-making levels of the U.S. Government to enhance our nation's technological strength." Eckert retired from IBM in 1967 (although he continued to work out of an office at the Lab), and the same year Garwin was succeeded as director of Watson Lab by Koenig, who had been assistant director since 1965. In order to continue to devote time to his research in biophysics while serving as director, Koenig named Aisen as manager of biological sciences and medicine; Gutzwiller as manager of theoretical science and computing; and Redfield as manager of experimental physics and biophysics.

As the 1960's drew to a close, and the Watson Laboratory at Columbia neared the quarter-century mark, there began a re-assessment of its role in the company.



Top: Richard L. Garwin, Directory Watson Lab from 1966 to 1967, is nationally recognized both as a scientist and consultant to the U.S. Government on military and civilian problems.

Bottom: H.K. ("Ken") Clark checks through a 25-year accumulation of records and memorabilia as the Watson Lab closing approaches.

On the basis of all these considerations, Columbia and IBM reached an agreement in mid-1969 to close the Watson Laboratory in the fall of 1970, with the research activities at the Lab to be transferred to the Research Center at Yorktown. The long-standing relationship between Columbia and IBM was to be maintained by continued appointments of Research staff members to the Columbia faculty, opportunities for graduate students to do their thesis work at the Research Center, and visits and personal contacts between faculty and staff members. The decision was announced on August 6,1969, and during 1970, the research activities of the Lab were gradually relocated in a section of the Research Center especially set aside for the "Watson Lab" group. In a message to the Research Division, Dr. Arthur G. Anderson, IBM Vice President and Director of Research, said: "The Watson Laboratory at Columbia University has had a distinguished career in IBM as an early and major contributor to our programs in computers and scientific computing, solid state physics, and more recently, life sciences. Many of the methods we use in our research, and much of the life style we practice today throughout the Division, trace their origin to the people and the life style of the Watson Laboratory... With a continuing strong relationship with

[-51-] Fresh appraisal of the historical reasons that had formerly justified the maintenance of an IBM facility at Columbia indicated that many of them were no longer valid. Where the laboratory had once been the ccrmpany's only strong link with the academic and scientific world, there had since developed many such links. At both the Yorktown and San Jose Laboratories, numbers of staff members held visiting appointments at universities, taught courses and supervised graduate students. Moreover, the evolution of computation from a laboratory art to a highly professional activity, and tne establishment by Columbia of its own computing center, had eliminated any advantage to either Columbia or IBM in maintaining computing facilities at the Watson Lab. At the same time, the development of the extensive resources of the Yorktown laboratory so near New York would allow research projects under way at the Lab to be carried out equally well at Yorktown.

Columbia and other universities, we go now from Watson Laboratory phase I to Watson Laboratory phase II. As a member of Watson Laboratory from 1953-1958, I can recall many good times and many scientifically stimulating times during those years. I personally owe a large debt to that Laboratory and to its people. I look forward now to seeing my many friends from Watson Laboratory in Yorktown..."[21].

Testing ground for a generation of IBM scientists and engineers, birthplace of the NORC, familiar to hundreds who came to understand computers and went on to operate them all over the world, the IBM Watson Laboratory at Columbia University closed its doors late in September, 1970. *Multum in parvo.*

[-52-] [-53-]

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3. Speech delivered by Reynold B. Johnson, "A Testimonial to Dr. Ben Wood's Association with IBM," at a dinner on May 11, 1965.
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6. IBM Oral History Project on Computer Technology, Interview TC-1, with W.J. Eckert, July 11, 1967.
7. Ibid.
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9. IBM Oral History Project on Computer Technology, Interview TC-1, Part II, with W.J. Eckert, July 20, 1967.

1. Remarks by Byron L. Havens at NORC dedication luncheon, December 2, 1954.
2. IBM Oral History of Computer Technology, Interview TC-30, with J. Jeenel, November 2, 1967.
3. Peter J. Price to the author.
4. Fred Holzberg to the author.
5. IBM Oral History of Computer Technology, Interview TC-1, Part II, with W.J. Eckert, July 20, 1967.
6. Ibid.
7. Alfred G. Redfield to the author.
8. *IBM Research News*, Vol. 6, No.21, November 10, 1969, pg.1.

10. Columbia University Bulletin of Information, Forty-sixth Series, No.14; March 2, 1946.

11. IBM Oral History Project on Computer Technology, Interview TC-8, with R.R. Seeber, August 15, 1967.

12. Ibid.

13. *IBM Record*, Vol. 36, No.2, April 1953, pg.4.

[-54-]

Appendix I: Honors to Watson Laboratory Members

Philip Aisen (1965-1970)
1966-67 Guggenheim Fellow

John Backus (1950-1952)
1963 IBM Fellow

Leon Brillouin (1952-1954)
1950 Member of the National Academy of Sciences

Wallace J. Eckert (1945-1967)
1966 James Craig Watson medal from the National Academy of Sciences for pioneering contributions to scientific computing and to lunar theory
1967 IBM Fellow
1968 Honorary Doctor of Science degree from Oberlin College
1969 IBM Outstanding Contribution Award for his contributions to lunar theory

Richard L. Garwin (1952-1970)
1962-66; 1969-present Member of the President's Science Advisory Committee
1966 Honorary Doctor of Science degree from Case Institute of Technology
1966 Member of the National Academy of Sciences
1966-69 Member of the Defense Science Board
1966-67 Member of the New Technologies Panel of the National Commission of Health Manpower
1967 IBM Fellow
1969 Fellow of the American Academy Arts and Sciences

Byron L. Havens (1946-1959)
1950 Presidential Certificate of Merit from President Truman for World War II work.

Martin Karplus (1960-1965)
1967 Member of the National Academy Sciences

Seymour> 1967 (summer) National Academy of Sciences Exchange Scientist to Yugoslavia

Alfred G. Redfield (1955-1970)
1970 IBM Outstanding Contribution Award for his High Resolution Pulsed Nuclear Magnetic Resonance Spectrometer

Llewellyn H. Thomas (1946-1968)
1958 Member of the National Academy of Sciences
1963 IBM Fellow
1965 Doctor of Science degree from Cambridge University

[-55-]

Appendix II: Columbia University Appointments Held by Watson Laboratory Members

W.J. Deerhake
1956-57 Adjunct Assistant Professor of Electrical Engineering

W.J. Eckert
1947-70 Professor of Celestial Mechanics

T. Fabry
1968-70 Adjunct Assistant Professor of Chemistry

R.L. Garwin
1954-57 Associate in Physics
1957-59 Adjunct Associate Professor of Physics
1959-present Adjunct Professor of Physics

M.C. Gutzwiller
1963-67 Adjunct Associate Professor of Metallurgy
1967-present Adjunct Professor of Metallurgy

E.L. Hahn
1953-55 Associate in Physics

M. Karplus
1960-63 Associate Professor of Chemistry
1963-65 Professor of Chemistry

S.H. Koenig
1957-59 Adjunct Assistant Professor of Electrical Engineering
1959-65 Adjunct Associate Professor of Electrical Engineering
1965-68 Adjunct Professor of Electrical Engineering
1970 Lecturer in Art History

J.J. Lentz
1956-58 Adjunct Assistant Professor of Electrical Engineering

T> 1967-present Adjunct Assistant Professor of Physics

A.S. Nowick
1958-59 Adjunct Professor of Metallurgy
(same appointment while he was at Yorktown 1959-66)

P.J. Price
1967-present Adjunct Associate Professor of Physics

A. G. Redfield
1956-63 Associate in Physics
1963-66 Adjunct Associate Professor of Physics
1966-present Adjunct Professor of Physics

Y. Sato
1960-62 Visiting Professor of Geology

L.H. Thomas
1950-68 Professor of Physics

R.M. Walker
1954-55 Adjunct Assistant Professor of Electrical Engineering
1957-58 Adjunct Associate Professor of Electrical Engineering

Not included are Watson Lab members who held such positions as assistant, instructor, etc. Also omitted are persons from other IBM locations who, although not members of Watson Lab, have been included in the Watson Laboratory Columbia University Announcement (catalog) for reference purposes.

[-56-]

Appendix III: Watson Laboratory Patents and Publications (1960-1970)*

Patents granted to Watson Laboratory members: 67
Papers published by Watson Laboratory members in recognized scientific journals (including 18 in the *IBM Journal of Research and Development*): 359

1965 Maurice Katz – "Electrical conductivity in heavily doped n-type germanium: temperature and stress dependence" – Sponsor: S. H. Koenig.

1965 H. Jerold Kolker – "Electric and magnetic interactions in molecules" – Sponsor: M. Karplus.

1965 Joseph Krieger – "Theory of electron tunneling in semiconductors with degenerate band structure" – Sponsor: P.J. Price.

Internal publications by Watson Laboratory members:
Research Reports: 133
Research Notes: 18

*Totals include incomplete figures for 1970.

Appendix IV: Columbia Graduate Students who received their Doctoral Degrees Under Watson Laboratory Auspices

The roster of these students, with the year their degrees were granted, their thesis subjects and sponsors is as follows:

1951 Carl C. Grosjean – "The exact mathematical theory of multiple scattering of particles in an infinite medium" – Sponsor: L.H. Thomas.

1953 B. Bakamjian – "Relativistic particle dynamics " – Sponsor: L.H. Thomas.

1954 Bernd Zondek – "Stability of a limiting case of plane Couette flow" – Sponsor: L.H. Thomas.

1957 D.H. Tycko – "Numerical calculation of the wave functions and energies of the 1^1S and 2^3S states of helium" – Sponsor: L.H. Thomas.

1958 Bernard Herzog* – "Free magnetic induction from nuclear quadrupole resonance; double nuclear resonance effect in solids" – Sponsor: E.L. Hahn.

1960 Eric Erlbach – "Penetration of magnetic fields through superconducting thin films" –Sponsor: R.L. Garwin..

1960 Miriam Sarachik – "Measurement of magnetic field attenuation by thin supeconducting lead films" – Sponsor: R.L.Garwin.

[-57-]
1961 George Whitfield – "Theory of electron-phonon interactions" – Sponsor: P.]. Price.

1962 Yi-Han Kao – "Cyclotron resonance studies of the Fermi surfaces in bismuth" – Sponsor: S.H. Koenig.

1963 E. Friedman – "Hyperfine fields in ferromagnetic and antiferromagnetic metals" – 1966 Ramish N. Bhargava – "Studies of the band structure in bismuth and bismuth-lead alloys by de Haas – van Alphen and galvanomagnetic effects" – Sponsor: S.H. Koenig.

1966 Andrew Cade* – "Binding of positive ion complexes to quantized vortex rings in liquid helium II" – Sponsor: R.L. Garwin.

1966 Andrew Kotchoubey – "Numerical calculation of the energy and wave function of the ground state of beryllium " – Sponsor: L.H. Thomas.

1966 Donald Landman – "The hyperfine structure of the metastable $^4F_{9/2}$ state of Au and Ag, the hyperfine structure of the metastable $^4P_{4/2}$ state of Cu, and the electronic g-factor of the metastable $^1D_2$ state of Pb, and the metastable $^2P_{3/2}$ state of Bi" – Sponsor: A. Lurio.

1966 Oscar Lumpkin – "Nuclear magnetic resonance in CuMn" – Sponsor: A.G. Redfield.

1966 Peter R. Solomon – "The relaxation of Mn and Fe ions in magnesium oxide" – Sponsor: A.G. Redfield.

1966 Kwong-Tin Tang – "Elastic and reactive scattering in the (H,H_2) system" – Sponsor: M. Karplus.

1967 Warner Fite – "Nuclear spin-lattice relaxation in super-conducting vanadium" – Sponsor: A.G. Redfield.

1967 Abbas Khadjavi – "Stark effect in the excited states of Rb, Cs, Cd. and Hg" – Sponsor: A. Lurio.

1967 Burton Kleinman – "A self-consistent field study of $KNiF_3$" – Sponsor: M. Karplus.

[-58-]
1968 Robert Hartman – "Temperature dependence of the low-field galvanomagnetic coefficients of bismuth " – Sponsor: S.H. Koenig.

1968 Alberto A. Lopez** – "Electron-hole recombination in bismuth " – Sponsor: S.H. Koenig.

1968 Robert Schmieder – " A level-crossing study of the $^2P_{3/2}$ states of the stable alkali atoms" – Sponsor: A. Lurio.

1970 (Tentative)

– Herman Bleich – "Nuclear magnetic resonance in proteins" – Sponsor: A.G. Redfield.

Sponsor: W.J. Nicholson.

1963 John J. Hall– "Large-strain dependence of the acceptor binding energy in germanium" – Sponsor: S.H. Koenig.

1963 Jordan Kirsch – "Doppler-shifted cyclotron resonance in bismuth" – Sponsor: A.G. Redfield.

1963 Martin Tiersten – "Acoustic mode scattering mobility of holes in diamond type semiconductors" – Sponsor: P.J. Price.

1964 Richard Hecht – "Electron spin susceptibility and Overhauser enhancement in lithium and sodium" – Sponsor: A.G. Redfield.

1965 Eric Adler – "Nonlinear optical frequency polarization in a dielectric" Sponsor: P.J. Price.

1965 A.N. Friedman – "Some effects of sample size on electrical transport in bismuth" – Sponsor: S.H. Koenig.

1965 Alan C. Gallagher – "Thallium oscillator strengths and $6d^2D_{3/2}$ state class="page" of hyperfine structure" – Sponsor: A. Lurio.

– James Burger – "The isotope shift in the ($2^1S_0 – 2^1P_1$ – line of atomic helium; the lifetime of the 2^1P_1 and the 3^1P_1 states of atomic helium " – Sponsor: A. Lurio.

– David de Santis – "The hyperfine structure of the $3\Sigma^+_u$ state of N_2" – Sponsor: A. Lurio.

– William Vu – "The effect of He^4 on exchange in solid He^3" – Sponsor: H.A. Reich.

– Albert Kung – "Nuclear Magnetic Resonance in Type II Superconductors" – Sponsor: A.G. Redfield

– David Hsieh – "Quasiparticle recombination and diffusion in superconducting aluminum films" – Sponsor: J.L. Levine.

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*Deceased

**Received his Ph.D. from the Swiss Federal Institute of Technology.

Appendix V: Watson Fellowships In Applied Mathematics

1947-48
James H. Mulligan & Margaret B. Oakley

1948-50
No candidates

1949-50
Carl C. Grosjean & William A. Johnson

1950-51
Carl C. Grosjean & Larry Siegler

1951-52
Donald MacMillan & Helmut Sassenfeld

1952-53
Donald MacMillan (no other suitable candidate)

1953-54
Salah Hamid (John P. Van Alstyne declined)

(1945-1970)

Aisen, Philip (1964-1970)
Albertson, B. (1961)
Allen, Richard G. (1957-1959)
Alsop, Joyce (1955-1959)
Arndahl, Lowell (1952-1955)
Anderson, Arthur G. (l953-1958)
Applequist, J.E. (1952-1953)
Arnold, Phyllis (1946-1947)
Ash, Carol (1956)
Astrahan, Morton (1956)
Backus, John (1950-1952)
Baker, Adolph (1948-1949)
Baumeister, Heard (1952-1956)
Beach, Ann (1947-1954)
Beckman, Frank (1951-1952)
Bell, Kenneth (1946-1956)
Bellesheim, Sara Curran (1966-1970)
Bennett, Richard (1946-1956)
Berkenblit, Melvin (1954-1960)
Blachman, A.G. (1956-1964)
Bland, George (1951-1960)

1954-55
Herbert Glazer & John W. Smith

1955-56
Kenneth M. King & John W. Smith

1956-57
Joe F. Traub (Betty Flehinger declined)

1957-58
Joe F. Traub (Mrs. Judith M. S. Prewitt declined)

1958-59
Joe F. Traub & Alfred H. Bennick

1959-60
Richard Balsam & Andrew Kotchoubey

[-59-]
1960-61
John Dimling and Steven Katz

1961-62
Henry Einhorn (Economics) (No other suitable candidate)

1962-63
Joel Moses & Paul Shaman

1963-64
Richard Francoeur (No other suitable candidate)

Blume, Richard (1951-1963)
Borders, C.R. (1949-1955)
Boyd, Edward (1960)
Brender, David (1955-1961)
Brillouin, Leon (1952-1954)
Brody, S.S. (1961-1965)
Brooke, A.W. (1947-1952)
Brown, Phyllis (1949-1952)
Brown, III, Rodney D. (1957-1970)
Bruner, L.J. (1959-1962)
Budnick, Joseph (1960-1962)
Bushman, Amy (1951)
Caron, Anne Flanigan (1954-1959)
Cedarholm, John (1952-1959)
Cheng, Tsung-Hsien (1957-1959)
Chow, Yuan (1960-1962)
Christian, Joseph (1956-1959)
Clark, H.K. (1946-1970)
[-60-] Clement, O.R. (1959-1970)
Codd, Edward (1949-1952)
Cohen, Arthur (1958-1959)
Corker, Gerald A. (1969-1970)
Cornish, Ruth Mayer (1949-1952)
Daehnke, Ralph (1951-1955)
Daly, Janice L. (1947-1952)

Deerhake, W.J. (1948-1956)
Dickinson, A.H. (1954-1955)
Digricoli, Vincent (1951-1952)
Donath, W.E. (1959-1962)
Dowst, Aetna Womble (1947-1952)
Drake, Edward (1952-1953)
Eckert, Wallace J. (1945-1967)
*Eichenberger, Norman (1951-1955)
Eisenstadt, Maurice (1958-1963)
Enlow, Paul (1951-1954)
Erlbach, Eric (1959-1960)
Fabry, Thomas (1965-1970)
Faden, Ben (1951-1959)
Farber, Arnold (1956-1959)
Fernalld, John (1946-1956)
Flehinger, Betty (1959-1960)
Fischler, A.S. (i961-1963)
Fleming, Paul (1957-1960)
Fortoul, Josie (1962-1970)
Franco, Albert (1957-1960)
Garwin, Richard L. (1952-65; 1966-70)
Ghosh, M. (1965-1967)
Gonda, Tibor (1957-1960)
Greene, Michael (1960)

*Jones, Rebecca (1946-1958)
Jones, William. (1952-1960)
Kamentsky, L.A. (1964-1968)
Karplus, Martin (1960-1965)
Kern, C.W. (1962-1964)
King, Kenneth (1957-1962)
Kinslow, Hollis (1951-1952)
Klugman, Arnold (1957-1958)
Knutson, J.S. (1965-1966)
Koenig, Seymour H. (1952-1970)
Kolchin, Eleanor Krawitz (1947-1951)
Kormanski, Michael J. (1950-1960)
Kotchoubey, A. (1966-1969)
Ladd, D.W. (1948-1951)
Lang, Norton D. (1969-1970)
Lentz, John (1946-1959; 1963-1969)
Levine, J.L. (1962-1970)
Lewis, Peter (1955-1961)
Liebman, Adele (1964-1970)
Lindberg, Libby (1950-1951)
Lurio, Allen (1957-1970)
Mace, David (1950-1959)
Masuda, Y. (1960-1961)
Mayhew, John (1949-1951)

Grosch, Herbert R.J. (1945-1950)
Gunther-Mohr, G. Robert (1953-1957)
Gutzwiller, M.C. (1962-1970).
Hahn, Erwin L. (1952-1955)
Haibt, Luther (1960)
Hallstead, Herbert (1954-1955)
Hankam, Eric (1945-1959)
Hansen, Mary Lou (1948-1949)
Hausman, Lillian F. (1945-1948)
Havens, Byron L. (1946-1959)
Heizman, Charles (1957-1958)
Hellwig, Jessica (1957-1958)
Herrick, Harlan (1948-1952)
Herrick, Marjorie (1946-1948)
Holtzberg, Fred (1952-1960)
Horton, John W. (1953-1959)
Hutto, M.J. (1965)
Jeenel, Joachim (1949-1959)
Jensen, Robert (1951-1956)

McClelland, William (1947-1952)
McDermott, Lillian (1953-1955)
Meadows, Harley (1952-1954)
Mecs, Eela (1960-1964)
Mertz, Robert (1950-1958)
Mico, George (1956-1959)
Miller, James M. (1960-1961)
Mitchell, George (1950-1952)
Morgan, Thomas (1957-1958)
Morrison, William (1951-1952)
Moss, Thomas (1967-1970)
Munick, Herman (1952-1953)
Munro, Ann (1959-1960)
Nethercot, Arthur H. (1957-1960)
Nicholson, Stephen (1951-1955)
Nicholson, William J. (1960-1968)
Noel, Charles (1956-1960)
Nowick, Arthur (1957-1958)

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*Deceased

O'Brien, Regina (1966-1970)
O'Toole, James F. (1951-1955)
Palmer, John H. (Jack) (1949-1957)
Palocz, Istvan (1957-1961)
Patlach, Alvin M. (1958-1968)
Paulsen R.C. (1954-1955)
Perkins, H. (1961-1962)
Pfaff, Robert (1956)
[-61-] Poley, Stanley (1955)
Porter, R.N. (1961-1962)
Price, Peter J. (1953-1970)
Quarles, Donald (1949-1952)
Rabinovici, Benjamin (1957-1959)
Rambo, Robert (1951-1958)
Redfield, Alfred G. (1955-1970)
Reeber, Morton (1960)
Reich, Haskell (1955-1970)
Reid, W.H. (1946)
Reisman, Arnold (1953-1960)
Robbins, Daniel (Dan) (1949-1953)
Rosenheim, Donald (1953-1960)
Rosenkrantz, Phyllis G. (1968-1970)
Rosoff, M. (1961-1964)
Rossoni, Giampero (1954-1957)
Roth, Robert (1954-1955)
Rothman, S. (1948-1951)
Sacks, Grace A. (1956-1957)
Sato, Yasuo (1960-1962)
Schillinger, Walter (1956-1910)
Schlig, Eugene (1956-1959)
Schlup, W.A. (1964-1966)
Schrader, D.M. (1962-1963)
Schreiner, Kenneth (1951-1959)
Schubert, Robert (1950-1954)

Smith, Eleanor M. (1956-1958)
Smith, Harry F. (1956-1967)
Smith, Merlin G. (1952-1958)
Solnit, Kenneth T. (1970)
Sovers, O.J. (1962-1964)
Stern, Emanuel (1953-1960)
Stewart, Elizabeth A. (1946-1952)
Strickland, Daniel (1954-1955)
Tainiter, Melvin (1960-1961)
Taub, Jack (1955-1958)
Testa, Frances (1958-1959)
Thomas, Llewellyn H. (1946-1968)
Thomsen, Donald Lo (1958-1959)
Titcomb, Lydia (1967-1970)
Tobin, Bernard (1951-1955)
Tomer, Eugene (1955-1959)
Toner, James W. (1946-1955)
Triebwasser, Sol (1952.195.7)
Tsang, M.Y. (1968-1969)
Tucker, Gardiner L. (1952-1954)
Volin, C.E. (1965-1966)
Von Gutfeld, Robert (1960)
Walker, M. Judith (1962-1966)
*Walker, Robert M. (1946-1960)
Wagner, E.G. (1959-1961)
Weddle, Meredith B. (1962.1963)
Weiss, Charles, Jr. (1969-1970)
Welch, Peter (1960)
Widmer, Hans (1955-1960)
Wilner, Antoinette (1960-1965)
Witzen-Geijsbeek, Margaret (1954-1960)
Wong, York (1960-1962)
Wright, Sylvia (1966.1967)
Zondek, Bernd (1950-1954)

*Seeber, Robert Rex (1945-1956)
Sharpe, Sylvia A. (1969-1970)
Shavitt, I. (1960-1961)
Sheen, H. (1961-1963)
Sheldon, John W. (1949-1952)
Siegal, Lucy (1951-1952)
Simon, Sanford B. (1969-1970)
Skillman, Sherwood (1947-1952)

*Deceased

[-62-]

Appendix VII: Roster of the Technical and Administrative Staff of the Watson Laboratory (1945-1970)

*Dutine, William J. (1953-59)
Douglas, William (1947-52)
Eisenstadt, Frone Lund (1960-64)
Fanelli, Patricia Maiberger (1963-67)
Feldhaus, John (1947-53)
Fern, Robert E. (1966-68)

Abbatecola, Robert (1950-60)
Adams, John (1954-55)
Agule, Barbara (1956-60)
Albert, W.E. (1960-70)
Albro, David B. (1956-59)
Alcantara, Barbara (1958)
Aleksey, R.J. (1957-62)
Alexandre, John (1965-69)
Arena, Angelo T. (1955-59)
Asai, Ken W. (1953-58)
Babu, Jennie M. (1954-55)
Ballardini, Louis (1954-70)
Barbanes, John E. (1951-54)
Baron, David G. (1955-58)
Barrett, Ethel C. (1954)
Berandt, Leonard J. (1953-59)
Best, Emogene Cobb (1951-56)
Bilelo, Maria A. (1959-63)
Blair, Edward A. (1952-53)
Bischoff, Jacqueline (1956)
Bonsignore, R.T. (1960-69)
Bravetti, Denise M. (1960-70)
Burch, Annabelle (1955-57)
Canning, John D. (1951-57)
Caracci, Donna F. (1959-61)
Carroll, D.A. (1969)
Ciriaco, Anne (1963-65; 1968-70)
Clausen, Olive Jean (1956-57)
Colpitts, Helen B. (1945-47)
Coney, George E. (1952-58)
Condon, Louise Ghiold (1966-68)
*Comell, Willard H. (1949-58)
Cozzo, Joseph (1950-70)
D'Amico, Theresa (1953-59)
Davis, Thomas (1953- 70)
Defranco, M.F. (1952-54)
Dohm, John C. (1951-58)
Donnelly, C.E. (1953-59)
Donnelly, Patricia Conway (1955-58)
Donnelly, Raymond C. (1952-56)
Doran, Joan E. (1953-56) Doty, P.G. (1951)
Doucette, Rhea M. (1953-54)

Finn, J.T. (1951-70)
Flynn, Patricia (1969-70)
Follayttar, Elizabeth A. (1955-56)
Foran, Marie Walsh (1957-64)
Fox, Henry C.. (1948-55; 1956-57)
Friest, Robert S. (1962-65)
Geoghegan, P.J. (1960-70)
Gloster, Richard J. (1959-60)
Grandia, Johannes (1956-59)
Griffiths, Richard D. (1946)
Harlow, Leslie A. (1946-55)
Harrington, Anne (1956-59)
Havens, Frances Schmidt (1953-55)
Hellwig III, Theodore A. (1955-59)
Heichlinger, Charles (1946-55)
Hess, C. Cynthia (1956)
Heyman, R.D. (1952-64)
Hickey, J.M. (1950-55)
Hickman, Katherine (1947-48)
Himmel, Richard P. (1956-59)
Hines, Emilie (1962-63)
Holohan, R.P. (1961-68)
Howe, Lynne C. (1963-64)
Janes, R.D. (1951)
Jones, L.F. (1963-66)
Jones, William P. (1952-59)
Kariya, Jean Ito (1947-54)
Kaszas, Kathleen J. (1952-57)
Kelbl, Alice Waara (1951-70)
Kelley, John (1949-52)
Kennedy, J.M. (1967-70)
Kenny, Edward J. (1953-59)
Kipp, R. W. (1969-1970)
Kiselewsky, William J. (1953-70)
Kolb, Jane Lace (1952-60)
Koste, Walter W. (1959-61)
Lagerstrom, Gertrude H. (1954)
LaGrotteria, A. J. (1956-60)
Lavin, John (1954-56)

*Deceased

Reese, Jr., William D. (1954-56)

*Lee, Richard (1953-60)
Lemke, Ann (dates?)
Lemke, James U. (Jim) (1948-50)
Leonard, Edward H. (1957-58)
Lewis, Lydia Kuharsky (1955-56)
Liggett, Julia W. (1956-57)
Limen, Maurice (1946-50)
Lionardons, H.M. (1950)
Lockwood, Philip G. (1951-59)
Low, Janine Leboullanger (1957-60; 1964-68)
Luhn, Hans E. (1956-59)
Mabrey, Jean M. (see Taylor)
Madonna, Edward J. (1954-56)
Magarinos, Isabel Maria (1962-63)
Mair, Lloyd J. (1958-70)
Maloney, Patrick J. (1953-61)
Manganarb, Louis H. (1962-70)
McGill, Luther (1965-69)
Melican, Louise Ryan (1953-62)
Meyer, Jerry (1955-57)
Murphy, Jean M. (1951-53)
Murray, Jane (1953'-55)
Myers, R.L. (1965-69)
Nornabell, Ursula V. (1947-53)
Osborne, R.R. (1967)
Ostrowsky, Nancy Haliczer (1967-70)
Ozimek, Stanley (1960-62)
Pantalone, J.G. (1957-60)
Parrish, James T. (1951-59)
Parry, Gloria H. (1952-53)
Payes, Norman (1957-68)
Payne, Clifford (1945-46)
Peel, Joe (1958-70)
Pfister, Christel Linde (1956-62)
Pierson, Robert K. (1951-54)
Plum, M.J. (1947-70)
Poley, Faith Lillibridge (1954-55)
Powell, Nancy Neff (1955-56)
Rauf, Charles P. (1953-55)
Rautenberg, Helen F. (1957-70)
Rogers, Mary (1953-70)
Rohr, Robert L. (1952-60)
Riog, Jaclyn H. (1953-55)
Rubenstein, Elaine F. (1960-62)
Rudnick, Cecile H. (1952)
Ryan, Mary E. (1954-55)
Samson, George (1946-52)
Savas, Helen A. (1956-62)
Schildnecht, Carol (1959-60)
Schmid, Ferdinand R. (1957-63)
Schmidt, Rudolph (1953-69)
Sellers, Rita C. (1952)
Severud, Christopher N. (1952-54)
Shapiro, Edith R. (1970)
Sierssen, John H. (1952-70)
Silverman, Sandra t 1955-56)
Sims, Janis M. (1945)
Smith, Elinore Nichols (1952-58)
Smith, John F. (1950-60)
*Stenbo, Lydia (1949-62)
St. Marie, Rita (1958-70)
Summers, Nancy Stevenson (1954-56)
Sutton, Robert (1950-51)
Sweeney, Kathleen Maher (1952-54)
Taylor, Jean M. (*née* Mabrey) (1950-51)
Terhune, Charles E. (1955-61)
Tether, Isabelle G. (1950-54)
Tomczak, Doris T. (1950-51)
Tommasi, Flavia Scolaro (1953-59)
Townsend, Anna M. (1953-55)
Ulrich, Richard P. (1955)
Vetterl, H.J. (1963-67)
Wagner, Viola Jean (1951-55)
Ward, Elizabeth E. (1945-51)
Weinberg, Irving (1946-47)
Whitehead, Betty Jean (1948-51)
Wilkstrom, M. Theodore (1954)
Woodley, James T. (1957-69)
Wu, P.J. (1969-1970)

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*Deceased

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Book design: Robert L. Monahon, Sr.