NATIONAL ACADEMY OF SCIENCES

HOWARD PERCY ROBERTSON

1903—1961

A Biographical Memoir by

JESSE L. GREENSTEIN

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H P Robertson

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January 27, 1903–August 26, 1961

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HOWARD PERCY ROBERTSON, one of the most original workers in relativity and cosmology, was born to George Duncan Robertson and Anna McLeod in Hoquiam, Washington, January 27, 1903. He died of a pulmonary embolism, after injury in a minor automobile accident, on August 26, 1961. To his many friends he was, and still is, "Bob," a warm memory of a good and great man, a patriot, and a scientist. At the height of his scientific productivity in 1939, he turned his attention to the military application of science and mathematics. He never fully cut his ties to such national and international service. He served both as Chairman of the Defense Science Board and as Foreign Secretary of the National Academy of Sciences, in his last year, while still lecturing on general relativity as Professor of Mathematical Physics at the California Institute of Technology. His public service may have reduced his scientific output, but his two lives together made him a complete and remarkable man, both admired and loved.

On his death in 1961, Detlev Bronk sent the following message to Bob's wife Angela:

> Distinguished scientist, selfless servant of the national interest, courageous champion of the good and the right, warm human being, he gave

richly to us and to all from his own great gifts. We are grateful for the years with him. We mourn the loss of his presence but rejoice in the legacy of his wisdom and strength.

BEGINNINGS

His family was middle-class, and his father, descended from a Scottish family of Maryland, became a well-loved county engineer, building bridges in a wide area of rural Washington. His mother, also of Scottish descent, attended Johns Hopkins and became a nurse. She was widowed and left with five children. Bob and his father had been very close, and Bob remained close to his MacLeod grandmother. Bob, only fifteen, was the oldest. Bob's mother became the local postmistress and was active in politics. Although Bob worked to help his mother support the family, he graduated from the University of Washington in 1922 and took a master's degree in 1923. All the children attended the University. He lived in a small lumber town, Monteseno, somewhat excluded by work from the normal youthful fun of university life. But in that same year, 1923, he married Angela Turinsky of Sandpoint, Idaho, the daughter of a captain in the Austrian Army who was by then a landscape architect in Idaho. She was born in Budapest, worked her way through the Idaho State Normal School, and had taught in a one-room schoolhouse before she became a student of philosophy and psychology at the University of Washington.

Bob's studies soon turned from engineering to mathematics and physics under the strenuous influence of the mathematician E. T. Bell and the University of Washington physicists. His relation with Bell was, and remained, a stormy one. Bell pressed him to take a graduate course by correspondence from the University of Chicago and helped him to find his real challenge by urging him to enter graduate work at the California Institute of Technology (Caltech).

After a few years of Bob's Caltech career, Robert A. Millikan brought his teacher, Bell, to Pasadena from Washington. Throughout their lives, and in spite of intense and clashing personalities, the relationship between them was deep. In his old age and illness, Bell was cared for daily by Angela and Bob, until Bell moved to his son's hospital. (Taine Bell was a physician in Watsonville, California.)

CAREER POSITIONS

From 1927 to 1929, Bob held the position of Assistant Professor of Mathematics. Between 1929 and 1947 he was Assistant, Associate, and then full Professor of Mathematical Physics at Princeton, with a sabbatical in 1936 at Caltech. After World War II, he became Professor of Mathematical Physics at Caltech (1947–1961). But as early as 1939, under the urging of Richard Tolman, he began to concern himself with what later became Divisions of the National Defense Research Committee and the Office of Scientific Research and Development (OSRD) (1940–1943). He was Scientific Liaison Officer of the London Mission of the OSRD (1943–1946) and Technical Consultant to the Secretary of War. In 1945 he was Chief of the Scientific Intelligence Advisory Section of the Allied Forces Supreme Headquarters. He received the Medal of Merit in 1946 for his contributions. From 1950 to 1952 he was Director of the Weapons Systems Evaluation Group for the Secretary of Defense, while continuing to teach relativity at Caltech. Another stay in Europe, as Scientific Advisor to the NATO Commander, occupied 1954 to 1956. After returning to Caltech he was Chairman of the Defense Science Board and member of the President's Scientific Advisory Committee. The strength of mind and body this career required was matched by his versatility. His wit, kindness, and ability to deal with all kinds of people survived the strain of these and the many other responsibilities now buried in the history of the enlistment of science in the art of war. I will discuss his scientific career separately, but when we see that most of his publications considerably predate our entry into the war, we must recognize how great a loss to science was his career of public service.

MATHEMATICS, PHYSICS, AND THE UNIVERSE

Robertson's scientific contributions were largely derived from his interest and ability in differential geometry and group theory, which he applied to atomic physics, quantum physics, general relativity, and cosmology.

In 1925 Bob received his Ph.D. from Caltech and a National Research Council Fellowship to Göttingen, 1925–1928, which included a half-year at Munich. As a mathematical physicist in Germany, he met D. Hilbert, R. Courant, K. Schwarzschild, J. von Neumann, E. Wigner, E. Schrodinger, W. Heisenberg, and A. Einstein, and worked with some of them. The transition from Bell, Brakel, and Utterbeck at the University of Washington, through Caltech to Göttingen, meant a transition from engineering through pure mathematics to applications of mathematics in the "new" atomic, quantum, and relativistic physics. In this pursuit Bob had energy without bounds and a sense of involvement with the history of philosophy and science. Although capable of mathematical elegance, he worked through in detail solutions of some of the first classic, difficult problems of relativistic mechanics. His scientific work evolved parallel to his career. Although a student in mathematics, at Princeton he was in both the physics and mathematics departments. As a Caltech physicist he advised several generations of observing astronomers at the Mount Wilson and Palomar Observatories on the critical tests of relativistic cosmology, as had Tolman. Tolman and Robertson had the clarity of mind that permitted them to translate abstract mathematical concepts into terms physicists and astronomers could understand.

At Caltech he had a wide variety of friends such as Paul Epstein, Graham Lang, Willy Fowler, Ira Bowen, Todor von Karman, and, naturally, Bell. The early years in Göttingen and Munich in the great period brought fruition to his graduate study of differential geometry. Much influenced by Weyl, with whom he worked, he translated Weyl's *Theory of Groups and Quantum Mechanics* in 1931. His bibliography from 1924 to 1929 includes differential geometry, the theory of continuous groups, atomic and quantum physics, and general-relativistic cosmology. In Göttingen he was a good enough mathematician to impress Courant and, to quote Bob, "even Hilbert." American science and scientists had not yet attained international prestige, but Bob learned German well enough for student life and could even make a sufficiently elegant German pun to be printed in *Simplicissimus.* As if this was not enough the student's life, he rolled a barrel of beer through cobbled Munich streets at 2:00 A.M. and thus earned a police citation for "disturbing the citizenry." About this time he became friends with von Neumann and with Martin Schwarzschild (son of the relativist Karl) and later was instrumental in bringing von Neumann and Wigner to Princeton University.

Along with physicists like Heisenberg and Max Born, Bob had a short but important involvement with the growth of quantum theory, especially in the relation of quantum mechanics to the theory of groups, their representations, and commutation operators. The Göttingen period gave him an excellent knowledge of quantum physics, but relativity theory and its applications had the stronger, longer impact. At Princeton he had a long contact with Einstein. Bob's realistic philosophy, in spite of his mathematical skill, made him skeptical of those who "thought they could invent the universe out of their own head." Bob loved mathematics mainly for its application to physical problems.

In relativity he found his life work. He lectured on it for years; I have seen and studied some of his lecture notes, continually revised, modernized, and made more elegant. Pages of a detailed derivation in colored ink were refined to a few lines. One of his last, students, Thomas W. Noonan, prepared these notes as a book, *Relativity and Cosmology,* published in 1968. His discovery of the (first order) theory of the linear cosmological redshift dates from 1928. The creators of special and general relativity theory were faced not only by an immediate hostile reception, but also by a fundamental uncertainty intrinsic to the theory. Its application to the enormous real universe (of which our knowledge was and still remains so limited), required simplifications. Large-scale homogeneity and isotropy of the unknown are postulates. Progress requires some postulate of the uniformity of the universe of matter and space-time, called the "cosmological principle." A possible nonzero cosmological constant, which Einstein introduced as a complication into the field equations, took the form of a cosmic repulsion of unknown magnitude. In the theory of gravitation, the interaction of matter with the geometry of space occurs in the form of singular points (matter) imbedded in a curved space-time whose metric properties are to be determined. The propagation of a photon in this is along a minimal path, a geodesic. The solution for an empty universe could be static (W. de Sitter). In 1928 and 1929 Robertson developed fully the "postulate of uniformity" so as to obtain the complete family of line-elements from the theory of continuous groups in Riemannian space. These Robertson-Walker cosmological spaces are still fundamental; A. G. Walker rediscovered them in 1936, and W. Mattig studied their further consequences in 1957 and 1958. These metrics have a line-element and a geometry which is homogeneous and isotropic in space but which changes in time at a rate to be determined from physical considerations rather than symmetry arguments.

The early years of relativistic cosmology were marked by a great uncertainty: was the universe static or expanding (W. de Sitter, Hermann Weyl, A. Friedman, the Abbé G. Lemaître, K. Schwarzschild)? With a nonzero cosmological constant the universe may be stationary but is not static. Dynamic (expanding) universes, with zero cosmological constant, were possible and could be finite or infinite, and of positive or negative curvature. Knowledge, however, is limited to a sphere of finite radius; i.e., there is an event horizon. The *Review of Modern Physics* article in 1933 is a classical presentation of the problem and its solutions. With the assumed overall uniformity, Robertson's line-element depends on the local behavior of matter. "This rawest of all possible approximations may be considered as an attempt to set up an ideal structural background on which are to be superimposed the local irregularities due to the actual distribution of matter and energy in the actual world." The detailed working out of the consequences requires the close interplay of mathematics and physics. In 1933 he solved the field equations using the cosmological principle and mathematical ingenuity. His exact solution of the two-body problem, including the advance of the perihelion of an eccentric planetary orbit, has stood the test of time.

The final observational tests of Robertson's expressions have not yet been made in the larger universe. Such cosmological tests (by Allan Sandage and others) are major goals in the observation of galaxies, radio galaxies and quasars by the largest radio and optical telescopes. The first observational test involves the possible nonlinearity (after suitable correction) of the relation between the apparent brightness and redshifts. At present, other less practical tests involve the number of objects at a given brightness (the number-flux relation found by radio astronomers) and the apparent-diameter-redshift relation, all produced by non-Euclidean departures from the metric. For successful application, the evolution of brightness and size of galaxies in earlier phases of their history (at the "look-back time") is needed. For the deceleration parameter, nonlinear effects could appear significant at observable values of the redshift when we understand all evolutionary effects.

Robertson's interest in the prediction of these effects led him (1928) to predict a linear redshift-apparent magnitude (i.e., brightness) relation and even to plot the first such diagram from the sparse available data. Edwin Hubble, in 1929, independently discovered this relation, central to the observational approach to cosmology. Later followed cooperation between Tolman and Hubble in the early days of the observation of the expanding universe. With the 100-inch telescope and ordinary galaxies, Hubble was active when the observations reached out to 13 percent redshift; Milton Humason found objects at 20 percent, with the 200-inch. In 1956 Robertson took an active interest in the discussion of the redshift results of Humason, Nicholas Mayall, and Sandage at Mount Wilson, Palomar, and Lick. The discoveries of radio astronomy further enlarged horizons, and a galaxy at 46 percent redshift was found by R. Minkowski. Galaxies to over 60 percent redshift have since been detected. Sandage and others are searching for still more distant galaxies. The quasars (perhaps themselves symbols of a relativistic collapse or singularity) have been traced to over 350 percent redshift, but seem too variable in intrinsic luminosity to be as useful in determining cosmological parameters.

In 1953, Bob's paper discussing tests of cosmology on an "elementary" level characteristically issued from the California Institute of Technology and Supreme Headquarters Allied Powers in Europe. When Bob was working in Washington and Paris and also teaching in Pasadena, he still discussed consequences of evolutionary changes and proposed new tests of cosmologies and the still very weak evidence for nonlinearity in the brightness-redshift relation with observers at Mount Wilson and Palomar.

The complexity of the evolution of the brightness and colors of stars is compounded in predicting the global brightness and color of a hundred billion stars, as they are born and evolve. Galaxy observations look back halfway in time to the "beginning," and quasars to 90 percent. When the universe was younger and denser, galaxies probably interacted more, i.e., have not always been closed systems but may have grown in mass. The stellar part of galaxy evolution can be modeled, but the model for galaxy growth is new and only partly studied. A major novelty in observational cosmology that would have given Bob a special pleasure is the radio-frequency discovery of the 2°7 K all-pervading isotropic, background radiation, greatly redshifted evidence of the cosmic fireball soon after the beginning. This radiation was implicit in the work of Bob's friends, the Abbé Lemaître, and George Gamow; Gamow, R. A. Alpher, and Robert Herman predicted a nearly correct value, but it then seemed unobservable. The other major problem that has surfaced in relativity is the existence of singularities, discussed by Karl Schwarzschild. Now we are beginning with some confidence to study less-than-cosmic-scale singularities—black holes—by their effect on nearby matter. Galaxies, quasars, globular clusters, and even stars seem to be scenes of violent energy releases connected with fall into a singularity. Such complications make the straightforward answer to the "cosmological question" more remote, but present fascinating byways. A central question for observational cosmology is whether the second-order term in the expansion is positive, zero, or negative. This depends fundamentally on the density of matter; if the expansion is to be stopped, we must find some twenty times the matter that we now know. If the origin of inertia is the existence of an external universe, the latter must also be more massive than we think. Theoretical general relativity and cosmology are in full flower (partly based on the evidence of the violence of events) and in many areas still rest on Robertson's work. Among his unpublished works Noonan lists: rigid body motion in special relativity, a study of Gödel's model, orbits around a variable mass, oscillation through a Schwarzschild singularity, and second-order plane gravitational waves.

Robertson's attention was not limited to tests of general relativity at the cosmological level. He was equally interested in solar-system tests of general relativity. Following the 1922 work of Arthur Eddington, no one had more to do in the early days than Robertson with developing a so-called "parametrization" of the spherically symmetric geometry about a center of attraction, to test general relativity by comparing its predictions with those of conceivable alternative theories of gravitation. In contrast to the line-element derived by Karl Schwarzschild from Einstein's standard general relativity for this geometry, Robertson analyzed a generalization of this geometry characterized by three disposable parameters. In Robertson's time and subsequently, and especially actively today, with the help of satellites and radar limits of greater and greater stringency are being placed on the departures of these three parameters from their Einstein values. One type of test has to do with the advance of the perihelion of an eccentric planetary orbit, especially the advance of the perihelion of Mercury. A second has to do with a precession of the local inertial frame of a small body in free orbit around the sun; this precession is predicted to have approximately three times the Newtonian value. It could be measured by a gyroscope in an artificial satellite. A third conceivable departure from Einsteinian predictions can be tested by the gravitational redshift of the photons of a light-ray. The accuracy of Mössbauer effect measurements of gamma rays confirmed this predicted redshift over a height difference of only 25 meters. It is also confirmed for white dwarf stars with lower accuracy, where it amounts to 0.02 percent. A fourth potential departure from Einsteinian predictions can be determined in principle by measuring the deflection passing the limb of the sun. This effect is of special interest because the Einstein value is twice the Newtonian value. Radio frequency observations of the apparent position of small radio sources as the sun passes near them have amply justified this prediction to one percent, and the less accurate stellar optical observations agree. Today at least ten effects are known that also allow tests of Einstein's theory and of such imagined variants from it as are describable by Robertson's now famous three parameters. The tests steadily improve in precision as the sophistication of measuring equipment increases. Clearly there will never be a last test. Will there ever be a first test to show a discrepancy?

Quite another relativistic effect interested Robertson and is the focus of attention in an ambitious experiment under preparation by Francis Everitt and William Hamilton. It concerns the Einstein-Mach theory of the origin of inertia. The Earth's rotation is expected to cause the rotation of the inertial frame—and the axis of a spin of a gyroscope in polar orbit around the Earth—by the fantastically small amount of about 0.1 seconds of arc per year.

Robertson delighted to talk also about what others have called the Poynting-Robertson effect. It has nothing to do with general relativity. However it also causes a departure of an orbit from the Newtonian prediction of constant radius. A small dust particle in orbit around the sun is constantly scattering sunlight. More photons are sent in the direction of travel than against it. In consequence, the particle suffers a small but significant backward push. This takes angular momentum away from the particle; therefore, the particle spirals inward toward the sun.

In cosmology, after the realization that the universe was expanding, i.e., nonstatic, and probably nonstationary, and contained material test points (galaxies), the important further step was to evaluate crucial tests of general relativity that might be supplied by observation. Robertson's papers from 1938 to 1940 were supplemented by detailed studies of methods of comparison with observation (1955).

A beautiful summary of the effects of general relativity and curved space in 1949 ("Geometry as a Branch of Physics") uses only school mathematics. He discusses the effects of space curvature on astronomical observables and says, "The success of the general relativity theory of gravitation as a physical geometry of space-time is attributable to the fact that the gravitational and inertial masses of any body are observed to be rigorously proportional for all matter." Note his characteristic approach: a test by external reality. He continued to study attempted revisions, Leigh Page's or E. A. Milne's static solutions and Fred Hoyle's steady-state solution, all with skepticism. He emphasized the basic importance of the Michelson-Morley and Ives-Stillwell experiments in reducing the number of postulates required.

No contribution that Robertson made to physics and astronomy is of more enduring importance than the geometrical line-element. A local space-time interval is a general mathematical expression with a meaningful separation of time-like and space-like coordinates. The "postulate of uniformity" was a necessary first approximation, stating in essence that matter and energy in the universe had no preferential axis and were on a large scale homogeneous and isotropic. The general class of Robertson-Walker line-elements predicts a first-order term, the expansion rate; a second-order term, the deceleration or acceleration of the expansion; and another second-order term representing the space curvature.

In this memoir I have not attempted to separate Bob's contributions at Princeton from those at Caltech. His greatest contributions to general relativity were made at Princeton University, and his greatest impact on astronomy at Caltech. I first met him when I was a Harvard graduate student attending his series of lectures at the Harvard College Observatory summer school in 1937. The lectures were unforgettable, as was his personality. One hot summer Sunday my wife and I managed to buy him bathing trunks still many inches too small for his massive frame. He talked our way into a private beach club on the North Shore. There we enjoyed a picnic, drinking wine which was a sudden gift from newfound friends. Bob later invited us to Princeton, where like so many people my wife and I were immersed in the Robertson household, near-neighbors of whom were the Johnny von Neumanns, and others of the influx of scientists from Hitler's Europe. Professor Hubert Alyea of Princeton recalls one such evening party at the Robertson home where Herman Weyl, John Wheeler, and Eugene Wigner were present, and the conversation turned to the analogies and differences between computers and brains. As the talk went on, von Neumann got more interested in analyzing the philosophy of a computer. When the party broke up at a late hour and he said goodbye, he stated that he was going to look into the matter further. That was the beginning of a famous chapter in history. Bob's distaste for pretense made parties with such stars comfortable for a graduate student and wife. Angela was full of stories about her work for the office of the overseer of the poor in the city of Princeton and as referee for the juvenile court. She has always remained enormously interested in people.

Bob took me to see Einstein. I completely failed, however, to communicate my small observational discovery about galaxies to that great, kind man. He shook his head and said the equivalent of "very complicated." It was in this important sense that Bob's approach differed from that late phase of Einstein's work. Things might be complicated but he would work them through.

He had become close friends with von Neumann and a diverse group from Moe Berg to Solly Zuckerman, Stanislaus Ulam, and Todor von Karman. An evening might be spent creating limericks or variants of known limericks and telling stories about the struggle between mathematicians and engineers. Bob once said, "I left Princeton because someone came better at limericks than I." He taught engineering mathematics, probably betraying both his pure-mathematics and his engineering colleagues, but his students gave him a bottle of Teacher's Scotch at his last lecture.

In 1947 Bob and Angela renewed our friendship by lending us their apartment in the Athenaeum (and a bottle of Scotch), when we came to see Caltech. He told me I should set up a department of astronomy, in connection with the completion of the Palomar 200-inch telescope. I obeyed.

We came to Caltech when Bob seemed nearly free from his responsibility to the military and to the nation. He had been elected to the National Academy of Sciences in 1951 and Foreign Secretary of the Academy in 1958. In spite of his difficult war experiences, he had developed a number of close friendships with Europeans, friendships which served him well after the war and in his position as Foreign Secretary. He traded birthday poems in German with Albrecht Unsöld of Kiel. Sir Solly Zuckerman was a frequent visitor from England to the house in Sierra Madre. Bob understood European university and scientific life and worked to rebuild it as Science Advisor to NATO. His service to the Academy is memorialized by the H. P. Robertson Memorial Fund, established in 1962 by a group of personal friends and companies he advised. The fund is used for a lecture on any topic, at the Academy meeting, every third year. The first Robertson lecture was, suitably, by John Wheeler, of Princeton, on relativity and geometry. Detlev Bronk gave an eloquent personal tribute. The next by Paul Doty, of Harvard, on "The Community of Science in the Search for Peace" was one that Bob would have enjoyed, on a topic to which he had given his life.

WORLD WAR II AND SCIENCE

The Society of Industrial and Applied Mathematics sponsored a symposium on cosmology and relativity in his memory in 1962. A letter from General Lauris Norstad, Supreme Allied Commander, Europe, in 1962 is quoted in A. H. Taub's memoir in the *Journal of the Society of Industrial and Applied Mathematics* (10:741–50).

> Dr. Robertson had a remarkable ability for getting to the crux of a problem and presenting his conclusions in such a manner that all could understand and appreciate them. He inspired the utmost confidence in all those who were privileged to work with him, and after his departure we frequently had occasion to call for his advice and assistance which was always forthcoming, frequently at great personal inconvenience and sacrifice. His contribution to the United States and the North Atlantic Treaty Organization was noteworthy and reflected his deep dedication to the ideals of the Free World.
>
> We at SHAPE [Supreme Headquarters, Allied Powers Europe] feel that we have lost a true friend and are most grateful for what your society is doing to keep his memory alive.

The great variety of national affairs to which Bob devoted so much of his life after 1938 is hard to describe; the military history of the contribution of science to World War II and the relation between British and U. S. operations research and its aftermaths have not been written. He received the Presidential Medal for Merit in 1946 for "solving complex technical problems in the fields of bomb ballistics, penetrations and patterns, and enemy secret weapons." Sir Solly Zuckerman mentioned Bob's work in England with R. V. Jones on scrambling radar beams and beacons. Bob was deeply involved with British colleagues in understanding the V-2 attacks and with the effectiveness (or lack of it) of large-scale strategic bombing on military production. In spite of his apparent ease and self-confidence, those important issues placed severe stress on what, underneath the jolliness, was a sensitive, temperamental, and humane personality.

In addition, he had a warmth centered on a long, romantic, and happy family life. Continuing her studies in philosophy when she was with Bob in Germany, Angela had become a psychological social worker for the city of Princeton and raised their two children, George Duncan, who is a surgeon in Arizona, and Marietta, wife of Caltech historian Peter Fay. In spite of the strain of the continual family separations forced by Bob's activities in Europe and Washington, Angela was always ready with food, drink, and wise, good talk for Bob's many and varied friends at home in Princeton and later in Sierra Madre. All became *her* friends and so remain. There are now seven grandchildren.

I am fortunate in having an outline from Frederick Seitz of the American side of Bob's career in defense, in the post-World War II development of military and basic research, and of the federal support of science. This phase covered over twenty-two years, longer than he had for his own fundamental contributions to science. Since his activities were so long and complex, I quote below Fred's letter to me (dated August 27, 1975) with only minor deletions. As all accounts of Bob's life and work are, it is a personal, warm recognition of the fullness of Bob's personality.

I first met Bob Robertson when I went to Princeton for graduate work in January of 1932. He was already established as a distinguished mathematical physicist, particularly for his work in cosmology. He was widely admired among the students as a gifted lecturer. Since we both came from the West Coast he went out of his way to note my presence in a somewhat bantering manner. I never worked closely with him on any research problem and in fact I do not think he ever had any thesis students at Princeton. As you know he was always somewhat temperamental and could combine humor with sharp disputations on matters scientific or political when the spirit moved him. Although he liked to appear hail-fellow-well-met, and even garrulous at times, later experience suggested to me that he had strong aspects of the loner. His great forte in physics was mathematical elegance and, unlike Johnny von Neumann, he rarely dabbled in a quantitative way with relatively mundane problems. Back-of-the-envelope calculations were not his style.

I was at the University of Pennsylvania by the time World War II broke out in 1939. Robertson was one of a small group at Princeton, which included Harry Smyth and Walker Bleakney, which started work with the government on problems of conventional ordinance. I was asked to join them and we began by spending a certain number of days per month worrying about problems related to the effectiveness of explosives, ballistics and the like. This association eventually grew into Division 2 of NDRC [National Defense Research Committee] and became headquartered on the east side of the fountain court on the main floor of the Academy [National Academy of Sciences].

In the very early war years Bob focused his research attention on the mathematical theory of explosion damage. He reviewed the rather voluminous literature available and tried to tie it together. After the fall of France in 1940, however, he was asked to serve as a liaison scientist with the U.K. and we saw less and less of him in the United States, although he did occasionally attend the steering committee meetings of Division 2 chaired by John Burchard. He was, of course, quite secretive about his official activities but it was clear that he was deeply involved in most of the important scientific issues connecting our government and the U.K. He moved to the U.K. full time in 1943.

Although I remained on the steering committee of Division 2 through most of the war, I joined the Chicago division of the Manhattan district in 1943 and gradually saw less and less of the group centered in Washington.

During the winter of 1944–45, when it was clear that the European phase of the war was nearly over, the Secretary of the Army decided to establish a field intelligence agency (FIAT) in Europe to study German technology and I was asked to become part of the staff. Bob had agreed to head the office and we met in France to pull the organization together. At that time he was in a state near physical and nervous exhaustion since among his numerous other activities he had headed the intelligence team which focused on the V-2 problem. Our office, although relatively tiny, was the focal point for an enormous amount of traffic as scientific intelligence teams from the U.S. and U.K. surged across Europe. Bob himself was the principle attraction for many of the visitors.

I returned to the United States at the end of the summer when it became clear that academic life would begin to get started again but Bob remained involved in Europe until well into 1946. Although he returned to Princeton it was clear that his life had been radically changed by the wartime experience. He continued to accept appointments for special studies usually at the Secretary's or Chief of Staff's level. Among other things he helped set up the Weapons Systems Evaluation Group which was advisory to the Chiefs of Staff on matters involving science and technology. This organization eventually became a component of the Institute for Defense Analysis. As a sequel to this he spent 1954 and 1955 in Paris as Scientific Advisor to the Supreme Allied Command in Europe.

Conant, Bush and K. T. Compton had recommended the creation of the Research and Development Board [RDB] with the Department of Defense to replace the work of the Office of Scientific Research and Development. When it became clear in the mid 1950's that a large full time staff, such as the RDB had, was really out of place in the Pentagon, a Defense Science Board composed of part time advisors and representatives from various agencies and organizations, including the National Academy of Sciences, was created to take its place. Bob not only helped in the process of pulling the DSB together but was its Chairman from 1956 to 1960. I served on study panels of the DSB. Bob was quite remarkable as a chairman, but not merely because he had a comprehensive understanding of large areas of military planning, particularly those involving research and development. He was also widely admired as an individual. In a sense he shared the somewhat unusual type of position both von Neumann and von Karman held in governmental circles. The roster of participants in his day represented something in the nature of a Who's Who in the appropriate circuit.

Following Sputnik and the agitation produced by it in the United States, Bob spent an extended full period in Washington as one of the key White House advisors, being attached to the PSAC staff.

I was appointed Science Advisor to NATO in 1959 when the headquarters were still in Paris. Bob not only came regularly to the quarterly meetings of the Science Advisory Committee of NATO, but passed through

Paris on innumerable missions both for the Department of Defense and other Washington based agencies. Looking backward I would judge that the opportunity these jaunts gave him to see many of his old associates was as much an incentive to travel as was his interest in the problems involved.

At the time I returned from Paris at the end of the summer of 1960, he declared that he was going to give up his Washington connections and remain in Pasadena. I am not certain whether he would have been able to do this to the extent he hoped, but his unfortunate and premature death closed the book on the issue.

I WOULD LIKE to thank Mrs. H. P. Robertson and Professor Frederick Seitz for their kind reminiscences and my wife for editorial assistance.

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