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Elizabeth Scott: Scholar, Teacher, Administrator

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Elizabeth Scott was born on November 23, 1917 in Fort Sill, Oklahoma, while her father was stationed there during World War I. This was an unlikely start for a girl who was to become an eminent scholar and researcher, a valued teacher and mentor to generations of students, a good friend to many colleagues throughout the country and a pioneer in the struggles for equality for women in academia. When she was only four years old, her father retired to study law, and the family moved to Berkeley to be close to the university. From that time on, her life centered around the University of California, Berkeley. In due course, Scott entered University High School. Henceforth, she was on the path to a career that encompassed a wide variety of interests, contributed much to knowledge and involved work with a large array of collaborators over a span of five decades, until her death on December 20, 1988.

THE EARLY YEARS

University High School in the 1930s was clearly an unusual place, which probably played a significant part in shaping Scott both personally and professionally. It was located in Oakland, and because of a policy of admitting children from the immediate area automatically, and those from other districts only selectively, it had a racially balanced population. The school was well financed, with foundation support for experimental programs and courses and considerable emphasis on training student teachers. There was substantial emphasis on an academic curriculum, preparing students to go on to college. This was clearly an environment conducive to the development of a youngster with a keen mind and sensitivity to social issues.

It is also clear, however, that Scott herself was exceptional even in that environment. Among these college-bound students, she was the only girl in the advanced mathematics courses that were offered. She was already thinking of becoming an astronomer. Although she also was considering a career as an artist, she was obviously willing to do what was necessary to prepare herself for a challenging, demanding profession that few women considered entering in those days. She found out that it was a profession not quite ready to welcome women.

Upon finishing high school, at a time when the big depression was not yet over, her family may have had more than their share of financial problems (her father had lost much of his eyesight in a serious automobile accident), so the University of California at Berkeley was certainly the most logical choice for Scott. Not only was the tuition extremely low, but also she was able to live at home and walk to campus.

Like many college students do, Scott joined a sorority. Unlike many others, however, her priorities were such that when the mandatory meetings of the organization coincided with an astronomy course she had signed up for, she stopped being an active member, never to return. But she continued to take astronomy courses and, upon receiving her bachelor's degree, went on to graduate work.

Through her years as an undergraduate, she had no women professors, except in physical education. At times, however, there were women substitutes when regular faculty were temporarily absent. It was on such an occasion that she met Pauline Sperry, one of the two women in the Mathematics Department at that time, who later gathered together several women graduate students and took them to lunch in the Women's Faculty Club. Scott was to have a long and active association with this group after she joined the faculty.

Just as there were few women mathematicians, so there were few women graduate students in mathematics, even during World War II. Their representation was somewhat greater in astronomy, yet they faced discrimination of a sort that was unusually harsh even for those early days. Women were explicitly forbidden to use the telescopes at Mount Wilson, which housed all the large instru-

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ments in California. Nor were there any women on the staff at the Mount Wilson and Palomar (now Hale) Observatories. The only role they were permitted was that of assistant. These women essentially did work that today would be called programming. They were sufficiently discouraged that they urged Scott not to get a Ph.D., for she would then be overqualified for the only type of position a woman could expect to get in astronomy.

Many years later, Scott continued to believe they were right in their judgment that she would not be able to get a job in her chosen field. Thus, even though she was fortunate in having a supportive Chair in her department, who arranged summer assistantships for her (not only at Mount Wilson, but also at Lick Observatory, where she did have access to telescopes), she became increasingly involved in work that resulted in an appointment as assistant professor in the Department of Mathematics in 1951 and a life-long commitment to statistics, applied to several fields in addition to astronomy.

RESEARCH AND SCHOLARSHIP

One of the decisions made during her graduate student years that turned out to be a major influence on Scott's career was that of giving up her teaching assistantship in order to work on a war-related project with Jerzy Neyman. He was already a member of the faculty, de facto head of the statistics group within the Department of Mathematics and well on the way to earning a reputation as one of the most renowned statisticians of his time. She began as one of his research assistants. Initially, he was the teacher and mentor, supportive of talented young people, women and men alike. Soon, however, their relationship became that of collaborators, each influencing and complementing the work of the other. The relationship lasted a lifetime, and many of Scott's publications are joint ones with Neyman.

Her early articles, the first of which was published in 1939 when she was only 22, long before she obtained her Ph.D. in 1949, were concerned

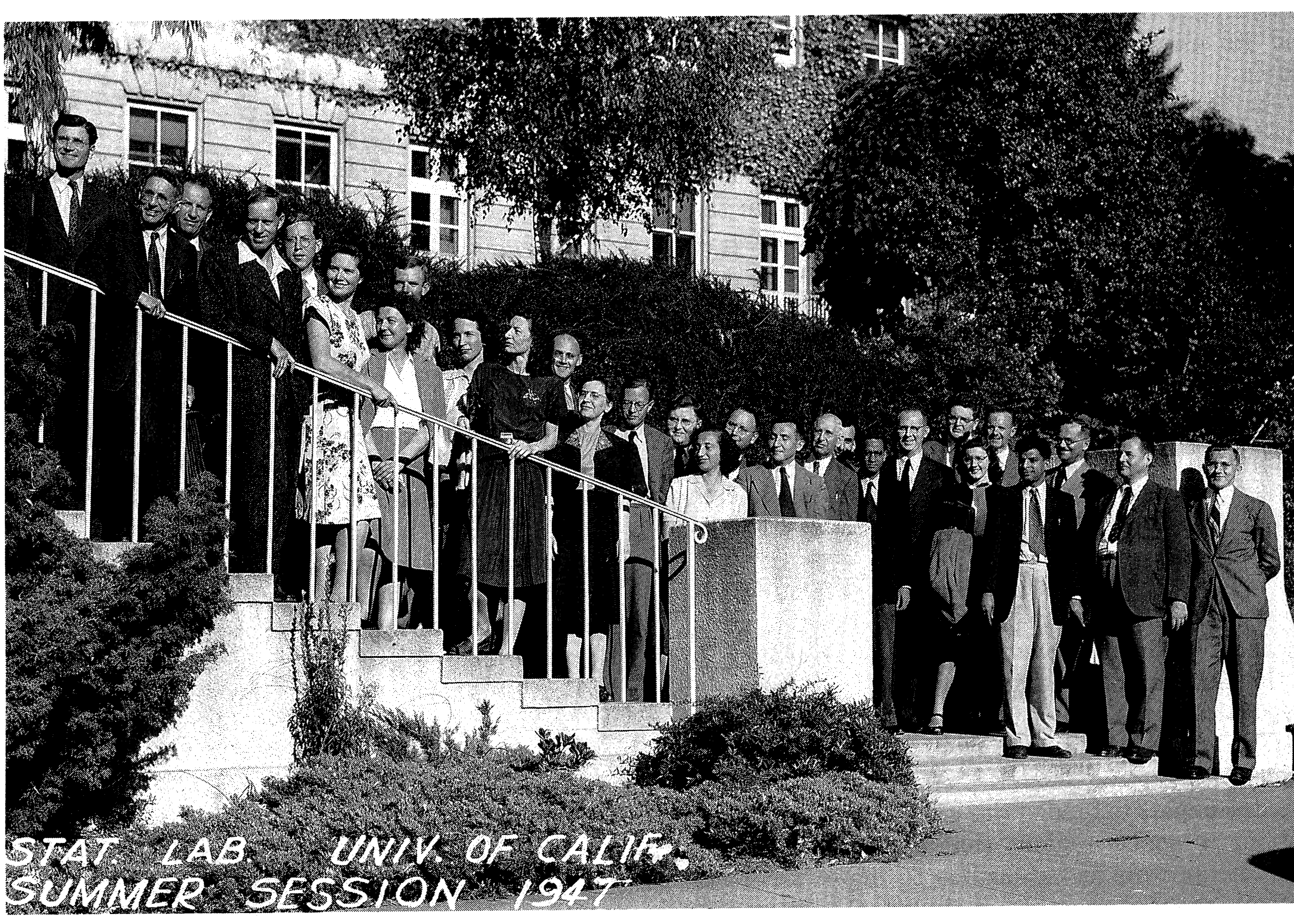

FIG. 1. *Statistical Laboratory, University of California, Berkeley, Summer Session,* 1947. 1. *E. L. Crow*; 2. *E. S. Keeping*; 3. *V. Lenzen*; 4. *D. G. Chapman*; 5. *C. Stein*; 6. *E. Crow*; 7. *E. Fix*; 8. *S. W. Nash*; 9. *E. L. Scott*; 10. *D. Cruden Lowery*; 11. *J. Gurland*; 12. *L. Elvebach*; 13. *E. L. Lehmann*; 14. *T. A. Jeeves*; 15. *E. Seiden*; 16. *E. A. Fay*; 17. *B. Epstein*; 18. *T. Birge*; 19. *I. Blumen*; 20. *Unknown*; 21. *B. M. Bennett*; 22. *J. L. Hodges*; 23. *T. Hodges*; 24. *H. Cramér*; 25. *G. R. Seth*; 26. *J. Neyman*; 27. *H. Hotelling*; 28. *Z. Szatrowski*.

with comets. She was to continue writing on various topics in astronomy throughout most of her career. It is a measure of the extent to which she became an equal partner that she and Neyman published as much together in this field, one that was entirely new to him, as they did in statistics. At the same time, she also authored papers by herself and with other researchers.

Her scientific research began with 10 papers in pure astronomy in the period 1939–1941 and two more in 1946. Wartime assignments caused the interruption in publications. They did, however, also give her the opportunity to become acquainted with and fascinated by statistics and served to change the nature of her research thereafter.

Not surprisingly, the first foray into the statistical world was in her original area, and during the 15-year span from 1949–1964 she published over 30 additional papers in astronomy. The earlier ones focused on the use of statistical tools to answer important questions in that field, followed by a shift to work using astronomy as the motivation for and application of statistical ideas. This series of papers centered on the premise that the universe and its elements were products of random processes.

The first paper to espouse that theme [14] analyzed the distribution of 78 eclipsing and 341 noneclipsing binaries relative to the longitude of periastron (w) and eccentricity of orbit. From this start, Scott was drawn into a long-range study of the distribution of galaxies by the ruminations of the famous Lick Observatory astronomer Shane, who was curious about what he termed the "lumpy" distribution of galaxies and wondered what, or if, statistical laws could explain this phenomenon. Scott had established in her earlier papers that they were not uniformly distributed and now went on to develop the methods to characterize the clustering of galaxies. This problem continues as one of intense research today.

The initial paper [19] obtained the general formulae for the joint probability generating function of N_1 and N_2, then derived moments of N_i, where N_i is the number of galaxies that have an apparent magnitude less than some prespecified number m_i and are included in an arbitrarily located solid angle w_i, $i = 1, 2$.

Later papers extended the ideas to more than two regions in space, regions that may or may not be disjoint, as well as extensions to many other statistical properties. This included the important problem of discriminating between cosmological theories. Clusters of galaxies are important for measuring the geometry of the universe. When more distant clusters are observed, they tend to contain more galaxies. This observational bias means that galaxies of any rank will be intrinsically brighter in these more distant systems. This observational bias or selection effect was first pointed out by Elizabeth Scott and is commonly known as the "Scott effect."

FIG. 2. *Elizabeth Scott, 1972.*

This series of studies was highlighted by the reading of a major paper before the Royal Statistical Society in London [36]. In this paper the statistical community was accorded an excellent exposition of various aspects of astronomy before a major statistical theme was developed. Rather than relying on the deterministic approach so often utilized, this paper advanced the view that the universe, and in particular cosmological phenomena, should be seen as realizations of stochastic processes. More specifically, the underlying processes were stationary in three-dimensional coordinate space or, if time were to be included, in four-dimensional coordinate space. Interestingly, this concept is today, 30 years later, once again receiving renewed attention.

The probabilistic theories derived for the clustering studies led into new techniques to test whether the universe was stable/static or expanding. Since the photographic plate (on which the binaries were

FIG. 3. *Chin Long Chiang and son, Elizabeth Scott, M. Loève, Helen Steck and Evelyn Fix in* 1955.

"recorded") simultaneously displays the distributions of galaxies from widely different time periods, the density of galaxies should increase with its distance from the earth if the universe were expanding, but be the same, however far back in time the clusters might be, if the universe were stable. A statistical kinematic test of the stability of systems of galaxies was developed [23]. When this test was first derived, it was applied in 1953 to the Coma Cluster for which the necessary data (i.e., radial velocities and magnitudes) were available and showed no indication of expansion. By 1961, however (see, for example, [44]), it became apparent that expansion was a viable conclusion.

Simultaneous with the studies in astronomy, Scott became involved in rain stimulation or, more broadly, weather modification research analyses. The first substantial papers on the subject appeared in 1960, thus foreshadowing what was to become a major thrust of her work, with over 30 publications on the subject, primarily in the 1960s and 1970s. This interest persisted and resulted in two more publications in 1984 and 1985 [109, 112]. The latter of these was also concerned with yet another weather modification data analysis. Most of the studies in which she participated focused largely on well known studies in meteorology including the 1957–1959 Santa Barbara experiment, the 1957–1963 Grossversuch III and IV experiments and the 1960–1964 Whitetop experiment, but some papers also dealt with other major U.S. studies, viz., the ACN 1953–1954 Washington-Oregon study, the SCUD 1953–1954 East Coast experiment, the two Arizona experiments of 1957–1960 and of 1961, and with lighter treatments of Australian and Israeli experiments.

Before going on to consider Scott's particular contributions, it should be noted that there was a great deal of controversy about weather modification. In 1960 Petterssen (1960) concluded: "There is nothing in our present knowledge to indicate that the general circulation of the atmosphere, the distribution of climates and similar large-scale features can be influenced by man." Indeed Scott's own studies reflect some of these vacillating deliberations. This is perhaps best illustrated by her comments in 1970 [76], when she reports that after having started work on rain simulation in 1951 she became disillusioned by 1960, only to change her mind once again in 1964.

Subsequently a special session of the 1965 Fifth Berkeley Symposium was devoted to assembling and evaluating factual material from several countries. By 1970 it seemed that weather could be modified by seeding. Evidence was provided by significant *increases* in the Grossversuch III experiment and significant *decreases* in the Whitetop experiments. Nonetheless, difficulties remained, both meteorological and statistical. The latter included the obvious fact that it was not possible to obtain a measure of precipitation for both seeded and unseeded environments in the *same* storm; nor could it reasonably be assumed that different storms were approximately homogeneous.

There were also problems in designing experiments that would provide powerful statistical tests and result in the desired level of significance. Thus Scott's papers wrestled with seemingly unsurmountable obstacles. The primary statistical tools used were regressions, often with transformed, usually square root variables and asymptotically optimal tests, $C(\alpha)$ tests, applied to randomized experiments with predictor variables that could not be controlled. The $C(\alpha)$ test, proposed originally by Neyman, addressed nonstandard situations where no known most powerful test existed. The weather data, for example, were often fitted from a gamma distribution, so that normal distribution theory could not be applied. Furthermore, this is true even if a transformation could be found to normalize the data. Meteorological challenges required coming to terms with the need to produce specific effects, such as changing the amount of a particular form of precipitation.

It turned out that many of the apparently conflicting results could be explained by differences in the predictor variables used. It was not, however, easy to determine which predictor variables were important. Nor could it be clearly established, for example, how far and in what direction the seeding experimental measurements should be taken.

In addition, data were sparse, and experiments at times lasted for years. Scott's work showed effectively just how much statistical theory still remained to be developed in order to understand better meteorological issues, but it also suggested that further collaboration between meteorologists and statisticians could perhaps ultimately resolve the remaining questions.

Although, throughout her life, she continued to do work that would qualify as pure science, a great deal of what she did was concerned with problem solving. One of her most important contributions was related to her service on the Committee on National Statistics of the National Research Council, National Academy of Sciences, of which she was a charter member. In the view of her colleagues,

> Betty's broad interests and experience in applications of statistics were a great asset to the Committee in its early days, as the Committee sought to develop a program of studies and establish itself as a resource to the federal statistical system and other government agencies. The Committee needed members like Betty, with her broad knowledge, indefatigable energy, and, most of all, perseverance. [M. L. Straf, personal communication, 1989.]

When a request came from another Academy committee concerned with the environmental effects of supersonic planes to help them reconcile the conflicting and fragmentary evidence with respect to the possible increase in skin cancer, Elizabeth volunteered to chair a panel to investigate these issues.

> The panel consisted of an atmospheric physicist, a photobiologist, dermatologist, an epidemiologist, and another statistician. In addition, the panel drew upon the works of many other scientists. It was one of Betty's strengths that she could bring together so many different types of scientists, understand their language and points of view, and work with them toward a common goal.
>
> Characteristically, Betty threw herself into the problem of modeling how skin cancer increases with increased intensity of ultraviolet radiation, ferreting out every possible source of data that could be brought to bear on the question. Even if there were only a handful of observations or data collected under very incomplete methods, they might serve to corroborate a model or shed new light on our thinking. It was as if every observation had some piece of information to contribute, and Betty was going to extract it. To the surprise of everyone, but perhaps not Betty, those data that she hunted down fell in line.... The question became not whether, but rather to what extent.
>
> But the question of predicting how much skin cancer would increase seemed more than formidable. It seemed impossible! There were myriad intervening factors, all attendant with large amounts of uncertainty. What wavelengths of radiation produce skin cancer? How do you take account of clouds, some of which absorb ultraviolet radiations? What are the effects of temperature and humidity? What are the effects of outdoor occupations and lifestyles that result in greater exposure to ultraviolet radiation? And how might all these factors interact? As if matters were not bad enough, there was not even agreement as to how the incidence of skin cancer should be measured.
>
> But to Betty, no problem was impossible. She would methodically set out to measure each and every factor, taking account of the uncertainties along the way. Her regression models in this and other studies became well known—for not being possible to fit on a blackboard. She seemed motivated by a belief that, by combing through clouds of irrelevancies, an underlying pattern might be revealed or that, at the least, we would better understand the uncertainties in the results of simpler models.
>
> The first report of the panel laid out the results of simple models for which the data of many sorts that Betty somehow obtained were in general agreement... Betty's exploration of more complex models, however, illustrated the enormous uncertainty in making predictions from the simple model.
>
> The other Academy committee wanted to accept only the results of the simple, more compelling model and refused to include in its

FIG. 4. *Elizabeth Scott with some young astronomers at Purdue University, 1975.*

report the results of Betty's more complex model. On a matter of principle, Betty appealed to Philip Handler, then president of the Academy. He agreed that the committee could not include just part of the panel's report; it had to be all or nothing. As a result, the entire report of the panel was included.

Predictions from the simple model were used for many years as the basis to evaluate the effects of threats to ozone from some aerosol propellants and refrigerants, nuclear detonations, fertilizers and other chemicals. Recently, DuPont announced that it will produce an alternative to Freon as a refrigerant. We have gone from an hypothesized reaction of stratospheric chemistry to a major change in the production of a popular chemical by a multinational corporation—all within a lifetime and not as the result of a catastrophe. This illustrates a unique contribution that science can make to society and is a befitting illustration for the contributions of Elizabeth Scott. [M. L. Straf, personal communication, 1989.]

Her interest in the possible effects of ultraviolet rays in causing cancer was to continue. She published a number of additional papers on this subject over the next decade, and also on other health matters related to carcinogens, as well as epidemiology. At the same time she continued giving her attention to other environmental concerns, most particularly cloud seeding and weather modification, matters that are becoming all the more important as scientists and policymakers alike are increasingly preoccupied with the greenhouse effect.

These contributions would be more than enough to earn Scott a position of eminence. In addition, however, she also earned a special place as a pioneer in applying statistical methods to research on the status of academic women. At a time when many concerned and well-intentioned faculty women were merely turning out evidence that they were paid less than their male peers, she collaborated in studies employing multiple regression, an approach that was soon to be used by universities in making salary adjustments and that came to be widely accepted as evidence in lawsuits.

From the first paper in 1972, "Women in Higher Education—The Facts of the Matter" [84], to "Developing Criteria and Measures of Equal Opportunities for Women" [91] in 1975 and "A 'Statistical' Remedy for Statistically Identified Discrimination" [105] in 1980, to name only a few, helping women to obtain equal access and equal rewards remained one of her goals not only as a researcher but also as a mentor and colleague. Scott was co-chair of a subcommittee of the Berkeley Senate which produced a 78-page report [77] in 1970. It was a comprehensive study of the status of women, including hiring, promotion and tenure, research opportunities, committee appointments and salary and benefits of faculty. It also provided information about admissions, financial support, graduation rates and other issues of concern to students. Considerable disparities in treatment were documented. Once the problems had been documented, she turned her attention to finding remedies.

FIG. 5. *Lucien Le Cam, Harald Cramér, Elwood Lyman, Kim Cramér, Elizabeth Scott, Berkeley, California, 1983.*

Scott was a major participant in developing the simple and easily used Higher Education Salary Evaluation Kit [92] published by the American Association of University Professors, intended to help in identifying and eliminating salary inequities. By 1990, scores of academic institutions had used this kit, and it had been upheld in the courts. Nonetheless, progress was slow, and Scott at times became discouraged. But she never gave up, and it seems particularly appropriate that her last professional presentation was the keynote address at a workshop for young women researchers in August 1988. It not only surveyed the record of the past but also offered encouragement and advice for the future (Billard, 1989, is to some extent an expansion of the idea presented in that address).

TEACHER AND FACULTY WOMAN

Some insight regarding Scott's teaching comes from Nancy Flournoy's comments regarding a visit at Berkeley. Scott had a graduate student working in the area of Flournoy's talk, and so Scott invited the student to join a gathering at the faculty club. Scott was persistent in encouraging the shy young woman to talk about her work. Scott was a bit frustrated by the degree of reluctance she found in her student. In a memorial to Scott, Flournoy goes on:

> My recent interaction with Betty was tremendously profound. It moved me and all the others in her presence. It was the night before the IMS meeting last Summer [1988] in Fort Collins, Colorado. Lynne Billard had organized a workshop for young women in academic statistics which I helped to fund during my tenure at the National Science Foundation. Mary Ellen Bock, Lynne Billard, Yash Mittal, and I had intensely debated the value of such a workshop. There was a concern that it would generate a negative reaction among the men in the community. But the beneficial aspects won and the conference came to be. It was a most moving experience for me, and a great deal of credit for its tremendous success is directly due to Betty. There are currently 15 women statisticians at the outset of their careers who have been deeply influenced by her and by this conference. [Flournoy, 1989.]

Scott was never reluctant to give of her time and energy, or to get involved in a controversial cause. One of these, of unusually long duration, was her involvement with the Berkeley Women's Faculty Club, which dates from the time when Pauline Sperry, a member of the Mathematics faculty, took a number of students to lunch there some time in the early 1940s. There were actually few activities at the club at that time, although in earlier days there had been regular meetings for presentation of academic papers, discussions, etc. Scott became an active participant through years of effort to make the organization as relevant and useful to women at Berkeley as possible.

Then, by the late 1970s, the question arose of merging the Women's Faculty Club with the Faculty Club, though at that time women were not even permitted in most of the dining rooms of the latter. (Today both men and women have the choice of joining either club.) In fact, Scott was "physically evicted from there more than once." She recounted one of these occasions, when she ate with a group that had made reservations for lunch there and had asked her to join them because they needed statistical advice.

> But . . . we hardly made any progress . . . at all when in came a man called Mr. Smith, who was a clerk, a counter employee. He ordered me to leave. Because I wasn't a member, therefore, I could not be eating in this room . . . I was angry and embarrassed, so I said, 'Well, you know that very few people in this room are members. Why do you pick on me?' He said, 'Because I can look at you and see that you are not a member. The other people I don't know.' (Actually, I think he knew every member very well, but that is detail.) Well, anyway they all got up and went out. And none of us paid. [S. B. Reiss, personal communication, 1981.]

In view of such episodes and persistent indifference to appeals to change this policy, it is not surprising that Scott and others were less than enthusiastic about the merger between the two clubs. In fact, she did her best to continue to support the Women's Faculty Club, well beyond the time when separate facilities for women and men on other campuses had long disappeared. In addition to ability, hard work and principled determination, loyalty was certainly among characteristics for which Scott was noted.

SUMMING UP

It is a measure of her success as a pioneer in a field where women have only gradually gained acceptance that Scott was Chair of the Statistics Department at her university in 1968–1973. She also attained many other prestigious positions. Among these was Vice President, American Association for the Advancement of Science, and Chair of the Section on Statistics, 1970–1971; Member of Committee on National Statistics, National Academy of Sciences, 1971–1977; Member of Executive Committee, Caucus for Women in Statistics, 1972–1973 and 1979–1980; Member of Board of Scientific Counselors, National Institute of Environmental

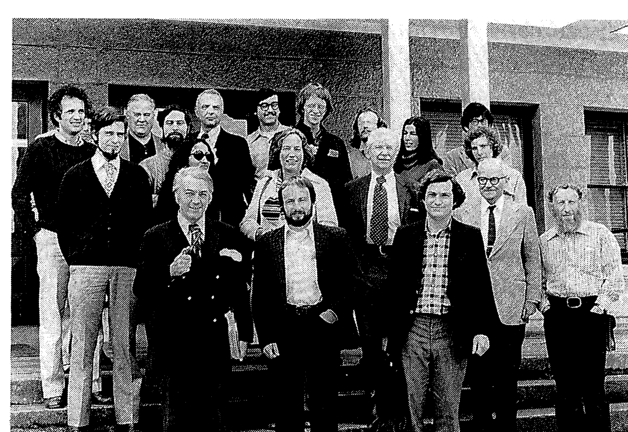

FIG. 6. *SIAM Institute for Mathematics and Society meeting, Stanford University, 1975. Front row (left to right): Geoff Watson, Peter Bloomfield, Persi Diaconis, Jerzy Neyman, and Ingram Olkin. Middle row: Don McNeil, Yash Mittal, Elizabeth Scott, (not known), and Jeff Brodsky. Back row: Brad Efron, John Tukey, Paul Switzer, Herb Robbins, Tom Sager, Bengt Berlin, Don Darden, Haiganoush Preisler, and Richard Olshen.*

FIG. 7. *Elizabeth Scott, David Blackwell and Erich Lehmann receiving "The Berkeley Citation" in 1988 at their retirement dinner and fiftieth anniversary of Jerzy Neyman's arrival and the start of Berkeley's statistics program.*

Health Sciences, 1973-1976; President, Institute of Mathematical Statistics, 1977-1978; Member of Committee on Education and Employment of Women in Science and Engineering, National Academy of Sciences, 1977-1983; Member, Science Indicators Review Task Force, National Science Foundation, 1977-1982; Outstanding Statistician of the Year Award, American Statistical Association, Chicago Chapter, 1980; Honorary Fellow of the Royal Statistical Society, 1981-; Vice President, International Statistical Institute, 1981-1983; President, Bernoulli Society for Mathematical Statistics and Probability, International Statistical Institute, 1983-1984.

This partial list of the positions in which she served is impressive by any standards. Everyone who was privileged to have known Betty surely learned to appreciate "her broad knowledge and interests, her ability to communicate and work with many different scientists, her indefatigable energy, her perseverance in ferreting out data, her determination in the face of seemingly impossible problems, and her resoluteness to academic principles." (M. L. Straf, personal communication, 1989.) She was indeed a very generous person, generously offering advice and assistance to all who sought it, including and most especially her students. Most of all, her friends will agree that Scott's passing meant not only the loss of a great scholar, but a concerned colleague and warm friend. As Miron Straf said, "This is how we knew Betty. This is how we loved her. And this is how [we] will remember her."

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