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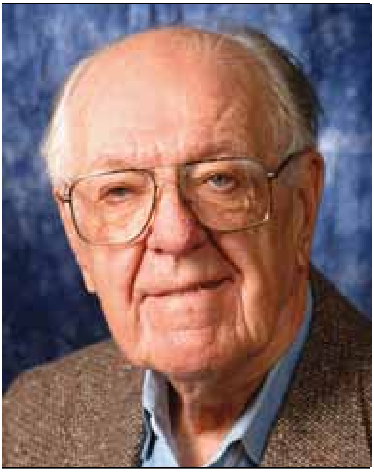
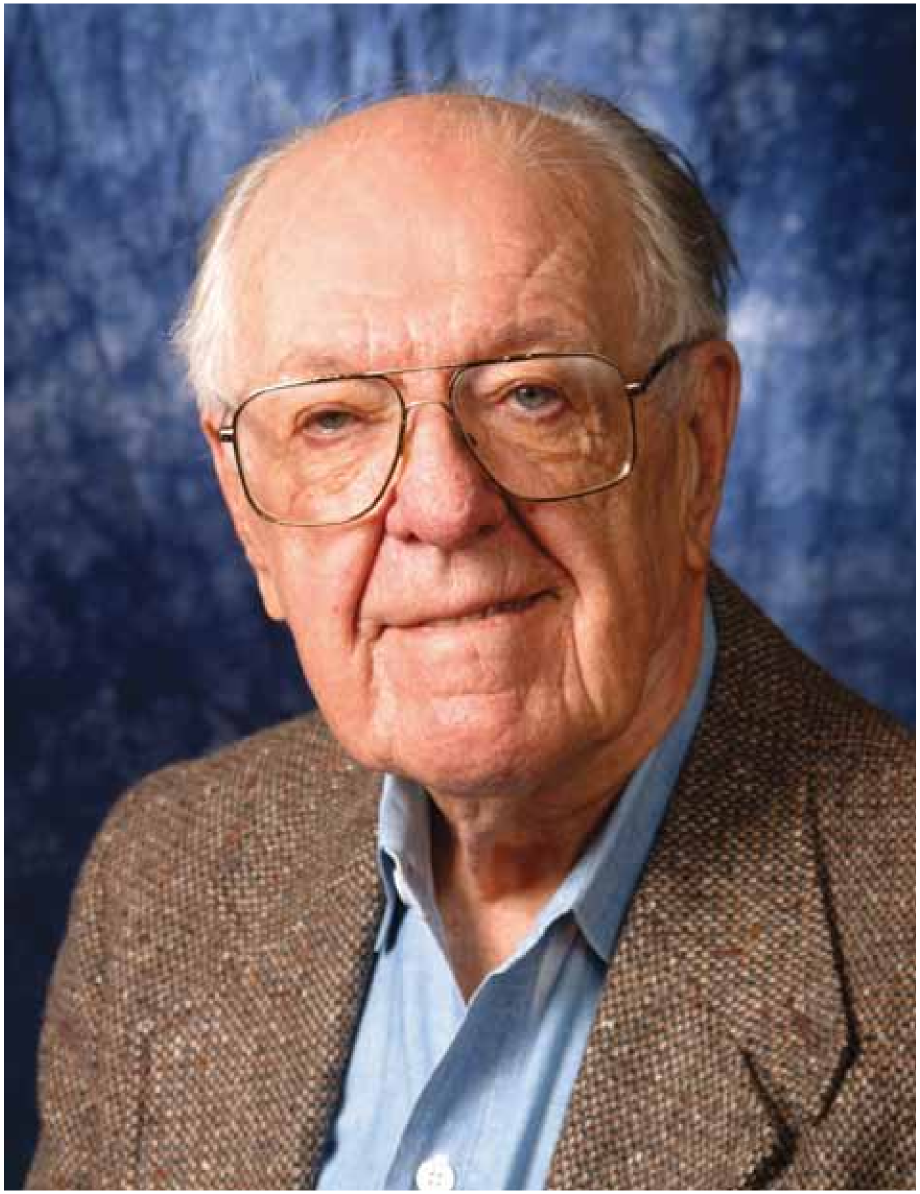


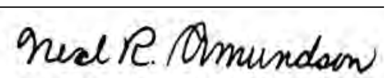
NEAL RUSSELL AMUNDSON

1916-2011

A Biographical Memoir by

ANDREAS ACRIVOS AND DAN LUSS





NEAL RUSSELL AMUNDSON

January 10, 1916–February 16, 2011

BY ANDREAS ACRIVOS AND DAN LUSS

Seldom has an individual exerted such a major influence in the development of an important field as was done by Neal Amundson to chemical engineering which, under his guidance and inspiration, was transformed, from a mostly empirical discipline straddling aspects of chemistry and mechanical engineering, into a branch of applied science that encompasses areas of the physical sciences, engineering, applied mathematics, computer science, and biology. This he accomplished by being: (a) an active researcher and author of numerous influential papers where he demonstrated that, by applying mathematical techniques, one can understand and predict the behavior of a large class of chemical processes far better than by following earlier empirical approaches; (b) a visionary chair of the Chemical Engineering Department at the University of Minnesota, which under his leadership achieved the top ranking on an international scale; (c) a very influential faculty member and university citizen at the University of Houston for close to another 25 years; (d) the American editor of *Chemical Engineering Science*, which became recognized as the journal in the field, as well as the editor of the *Prentice Hall Series in Chemical Engineering*; and, (e), a mentor to generations of PhD graduate students several of whom attained international reputations both in academia and in industry. His influence was not restricted to academia, however, in that the scientific approach to chemical engineering which he spearheaded eventually became the norm in the industrial practice of chemical engineering, particularly so among the major chemical and petroleum companies.

THE EARLY YEARS

Neal (who eventually became known and addressed as "the Chief" by his many admirers) was born in St. Paul, Minnesota as the only child of Oscar and Hazel Amundson (of, respectively, Norwegian and Pennsylvania Dutch ancestries). Oscar was a pipefitter, who managed to remain more or less employed throughout the depression and to support not only his small family but some of his brothers and sisters as well, while his wife ran the house. When he was four, at the insistence of his aunt Florence, Neal was enrolled at the Hancock School where he was greatly influenced by his second grade teacher, Miss McDonald, whom he always remembered with a great deal of affection. Upon receiving his 6th grade diploma, Neal continued on to Wilson Jr. High School and then to the St. Paul Central High School which had been the first high school to have been established in the state. According to Neal, St. Paul Central was the ideal high school at that time because of its high standards, the highly motivated group of students who were in attendance and its exceptional teachers especially in chemistry and math who, as Neal remarked on numerous occasions, were easily better than those whom he encountered at the University. Neal graduated 6th in a class of 658, of whom six of the top eight graduates went on to receive PhDs at the University of Minnesota (UM) in math, chemistry or engineering.

In 1933, Neal enrolled at UM where he supported himself by, as he put it, "pushing a broom". Initially, he intended to major in chemistry but, when he found out that he had to take organic chemistry plus the associated lab, he reconsidered and transferred to chemical engineering. At that time, the UM enjoyed a respectable reputation with some of its departments, in particular physics and chemistry, being known internationally. Unfortunately, chemical engineering, which was then located in the basement of the chemistry building was not in that category in that, aside from a young instructor, Burrell Ruth, who left shortly after receiving

Neal Amundson in 1937. Photograph courtesy of University Archives, University of Minnesota, Twin Cities.

his PhD, all the other members of the faculty (3 in all) taught by the book where formulae and facts were simply stated, but (as was typical in those days) seldom explained or justified. Neal ploughed on, received his B.S. in 1937 with high marks and then, again as was common in those days, went to work at an oil company, Standard Oil, in Baton Rouge, Louisiana. There he was assigned to the lubricating oil division where, as he recalled, he spent a great deal of his time writing reports. He did, however, enroll in several evening courses at Louisiana State University, one of which, on differential equations, taught by a "charming fellow" named Norman Rutt, made a big impression on him.

After two years, Neal, realizing that he was not cut out for a career in the oil industry, opted to try for an M.S. or, perhaps, a PhD, in chemical engineering and returned to UM in 1939 after attempting, unsuccessfully, to be accepted by MIT or other prestigious schools. The only financial support he could obtain was as a teaching assistant in the Mathematics Department of the School of Engineering, teaching two five-hour a week elementary courses for a total of $500 for the nine-month academic year. He received his M.S. degree in chemical engineering in 1941 but, having become disillusioned with the kind of research being conducted in the Chemical Engineering Department, decided to transfer to the Mathematics Department in the School of Engineering as a PhD student in math with Hugh Turrittin as his advisor. In Neal's own words, "nothing much happened" in the next 3 years, at the end of which he was offered the opportunity to go to Brown University for a year in order to finish his dissertation because his advisor was going to be on sabbatical and there was nobody else to look after him in his home institution. This, as it turned out, was a terrific break for Neal because at that time Brown was the center for applied mathematics and mechanics on an international scale with an outstanding faculty that included many leaders of the field (most of them Jewish refugees from Germany) and their disciples. Moreover, there existed a fantastic research spirit within that center, which attracted hordes of researchers from different backgrounds because it became known at the time that, if you needed to solve a difficult problem in applied math or mechanics, you had to come to Brown to do it. During his period at Brown, Neal also became acquainted with a number of leading mathematicians, such as Stefan Warschawski who, a few years later, became one of his mathematics colleagues in Minnesota. Thus, Neal's intellectual horizons were broadened in a very major way so that, when the year ended and he returned to UM in 1945, with a PhD and a faculty appointment as instructor in math, he was a changed man.

A year later, Neal received another lucky break which is difficult to imagine happening in today's environment. This came about because Charles Augustus

Mann, the long-time chair of chemical engineering, had heard through the grapevine that a number of leading chemical engineering departments in the US (e.g. MIT, Wisconsin, Delaware etc) had instituted a course in "applied mathematics for chemical engineers" and that this course had been well received by students. Not wishing to be left behind, "Doc" Mann then approached Neal, whom he had known from his years as a student in the Chemical Engineering Department, and asked him to teach such a course on a temporary basis. This "experiment" proved so successful that, at the end of the term, the whole chemical engineering class went to Mann and, unanimously stated that: (a) this had been, by a long shot, the best course that the class had ever taken in the department; (b) that the course should be taught on a regular basis; and, (c), that Neal should be appointed as a permanent faculty member of the Chemical Engineering Department. And so it came to pass that, in 1947, Neal was promoted to Associate Professor in Chemical Engineering with tenure even though his publication record at that time consisted of only one minor paper based on his M.S. thesis. This is how things were done sometimes in those days.

Soon after, the School of Engineering, which had been reorganized into the Institute of Technology with all the departments of engineering plus mathematics, chemistry and, later on, physics under its wing, acquired a new dean whose appointment had far reaching implications for the development of the Chemical Engineering Department as well as Neal's career. This new dean was Athelstan Spilhaus, a 37-year-old South-African-born MIT graduate who had already achieved an international reputation as a geophysicist and oceanographer for developing the bathythermograph that made it possible to measure ocean depths and temperatures from moving vessels. Spilhaus turned out to be a remarkable leader, a fine judge of people and a man of vision who transformed the Institute of Technology by making a number of exceptional senior faculty appointments including, as Head of Mathematics, Neal's acquaintance from Brown, Stefan Warschawski.

One of the first crises Spilhaus encountered was the death of Doc Mann in 1949, which left the Chemical Engineering Department leaderless. An obvious successor would have been Edgard L. Piret, an accomplished process engineer credited with developing the process for making the Army's K-rations during the war. Piret was already a full professor with a rising national reputation in chemical engineering circles but there was opposition to making him chair. So, Spilhaus decided to appoint Neal as "acting chair" and then went about trying to recruit an established senior "star" as he had just done for math. Although "everybody who was anybody" in chemical engineering was approached and many were actively courted, there were no takers and so, in late 1951, the unknown almost-36-year old

His applied math course became legendary among students even though it was very demanding, and was taught at 8 in the morning five days a week!

Neal Amundson was appointed Chair of Chemical Engineering and promoted to Full Professor. This, as it turned out, was an "appointment made in heaven" in that the newly appointed dean and the newly appointed chair got on together famously, with the result that Neal was able to proceed with his vision of creating a department of international stature knowing that his dean would support him unreservedly. In fact, on at least one occasion many years later, Neal made an offer on the spot to somebody whom he was in the process of interviewing, without even asking or having received beforehand the authorization for the position he was offering. This is the way things were done sometimes in those days!

A TEACHER AND MENTOR

As remarked earlier, Neal established a reputation among students as an exceptional teacher. This may sound surprising given that Neal was afflicted with a pronounced stutter that often made him stop his lectures or even his casual conversations in midstream. But he more than made up for this deficiency by being well prepared, by lecturing without notes, by being enthusiastic about what he was presenting, and last, but not least, by explaining everything clearly and in such detail that even the most unprepared students could follow him. In fact, Neal had developed the knack of pitching his lectures at the right level and making the subject interesting as well as challenging. His applied math course became legendary among students even though it was very demanding, and was taught at 8 in the morning five days a week! The course dealt with the application of conventional "bread and butter" mathematical techniques, e.g. Fourier series, Laplace transforms, orthogonal functions etc, to very specific physical problems of direct relevance to a range of chemical engineering processes so that the solutions to the corresponding idealized model equations had direct physical relevance and helped motivate the students. (In retrospect, it is a reflection of the times that, in the late '40's and into the '50's, the typical chemical engineering student entering graduate work had such a weak background in math that a course focused exclusively on the application of the techniques referred to above was considered to be "revolutionary" and "far out"). Moreover, since such tools were only applicable to a very restricted subset of linear equations, their usefulness was severely limited from the practical standpoint. But this was all that was available at that time given that numerical techniques were not of much practical value in view of the severe limitations of the then- existing computers, and that advanced asymptotic methods of analysis (e.g. inner and outer expansions, singular perturbations, etc, which would have been of great help in dealing with non-linear equations) had not, as yet, been developed to a sufficient degree of generality to be broadly useful.

Amundson portrait from 1955. Photograph courtesy of University Archives, University of Minnesota, Twin Cities.

Neal was also an effective communicator in a different way in that his papers are well written and a joy to read even many years after their publication. This may imply that his short stint at Baton Rouge writing (boring to him) reports for Standard Oil, were not such a waste of time after all!

Neal was an exceptionally successful mentor of PhD students. He gave them confidence at the beginning and just enough help for them to get started in their thesis work. He then left them to their own devices to "sink or swim," though he always looked after them and provided them with help and encouragement long after they had graduated. As Harmon Ray, who was not one of his students, pointed out:

> Neal was also responsible for recruiting the incredible group of PhD students when I was there. In my case, he sent me a telegram with an offer of admission with financial aid. No other school did that, and I was very impressed by the fact that this famous researcher and department chair would send me a telegram. Also, when I was a student there, I saw that he personally worked on evaluating PhD student applicants, in contrast to many other schools which just let some bureaucratic faculty member do that, with little, if any, input by the chair or the leading researchers. Also, since Neal taught all the incoming students, he got to know them on a personal level. He would then take an interest in them, initiate social conversations with them, and give them advice on career options. As a result, he was considered a friendly and supporting mentor by all the grad students who even named their intramural softball team after him: "The Chief's Army".

RESEARCH

On joining the ChE department in 1947, Neal was fortunate in being able to recruit, right off the bat, several talented PhD students who made it possible for him to establish an active research program in short order (one of his first students was Leon Lapidus who became a very successful academic, was elected to the NAE in '76 and was serving as chair of chemical engineering at Princeton when he passed away suddenly a year later). At first, Neal focused on two topics in the broad field of separation technology, specifically, (a) fixed bed adsorption, and, (b) stage-wise processes (primarily, distillation), both of which were considered "hot" subjects at that time.

The first topic, of which chromatography and ion exchange are well-known examples, refers to a process wherein two or more substances in a solution are separated from the solvent by percolating the former through a stationary bed of particles on which the solutes are first adsorbed, and then are desorbed when the flowing solution is replaced by pure solvent. When the flow rate of the solution is sufficiently low, this process is dominated by the thermodynamic equilibrium relation for each solute between the two phases. Hence, for most systems of interest, when a given adsorbed solute is desorbed back into the flowing solvent, it will exit the bed of stationary particles as a sharp band in a solution that is devoid of all the other solutes that were present in the initial sample. But, since practical considerations often require flow rates significantly higher than those that are needed for equilibrium between the phases to be established, one has to be concerned about the presence of non-equilibrium effects (such as, resistance to mass transfer, intra-particle diffusion of the adsorbed substances within the pores of the particles comprising the stationary bed, longitudinal diffusion due to velocity fluctuations within the bed, etc.) which would lead to a broadening of the bands and, potentially, to their partial overlap that would adversely affect the efficiency of the separation. All these effects were examined theoretically by Neal and his students (starting with Lapidus and ending with Rhee) for several decades beginning in the late '40's and are described in a series of landmark papers several of which are still being cited on a regular basis.

The second topic of Neal's research, stage-wise processes, is typically associated with distillation and extraction. Here, he focused on multi-component distillation and, specifically, on the then fashionable problem of how to compute the number of "ideal" theoretical plates required to achieve a desired separation into "light" and "heavy" components given the composition of the raw material, or "feed", and the so-called reflux ratio that denotes the fraction of the "overhead" or "light" vapor product, which is condensed and returned to the distillation column. Here, Neal's contribution consisted in realizing that the plate-by-plate calculations being carried out at that time could be performed much more efficiently using matrix algebra, a subject that was then totally unknown within chemical engineering circles! He, together with his student Andreas Acrivos, also solved analytically the problem referred to above for the case of a "feed" containing a continuous distribution of an infinite number of components for the special case when the so-called "relative volatility" of each component could be assumed constant, i.e. independent of temperature and composition. Eventually, Neal came to realize that such calculations could be performed much more readily using digital computers (which, although very primitive and of very limited scope at that time, were rapidly being upgraded) and he was one of the first to develop the methodology for carrying out this task.

At about the same time, Neal's research interests moved in yet a third direction as a result of Kenneth Denbigh's arrival at UM as a visiting professor in 1953. Denbigh, who was then a lecturer in chemical engineering at Cambridge University, had been trained as a physical chemist but had been converted into a chemical

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engineer while employed at Imperial Chemical Industries (ICI) as a research scientist. Denbigh had wide interests and was very intuitive in his approach, using simple arguments and a minimal amount of mathematics to describe physical concepts and processes. Through Denbigh's influence Neal became interested in the emerging field of reaction engineering which eventually became the main focus of his research. Neal was intrigued by this subject because at that time it was taken for granted by chemical engineers that at steady state and for a given set of parameters and operating conditions, the output of a process was uniquely determined by the composition of the input. In other words, it was believed that a given input led to a unique output everything else remaining the same. Although this is true for many processes, exceptions were recognized, first in the US by Lilneroth in the mid '20's and by Weber ten years later, but then elaborated on, in the 40's and early '50's, by Frank-Kamenetskii in the USSR, Denbigh in the UK and Van Heerden in the Netherlands who showed that, in the presence of a typically exothermic chemical reaction, the generation of heat coupled with the resulting temperature rise in the reactor could lead to the existence of multiple steady-states, several of which were stable (Lilneroth, for example, realized that this happens during ammonia oxidation on a Platinum gauze). In turn, this meant, that, starting from a given input, one should be able to obtain different products depending on the initial conditions! Although, in retrospect, this should not have come as a surprise given the highly non-linear relationship between output and input in chemical reactors, the possible existence of multiple steady-states was greeted, at first, with a considerable degree of skepticism within academic and especially within industrial circles. So, in 1953, Amundson embarked on a systematic research program in which he examined, via analysis but increasingly via computations, a large number of special cases and succeeded in establishing that, in processes involving chemical reactions, the existence of multiple steady-states is the norm rather than the exception. Moreover, he was able to show that, in some cases, a reactor will not attain a steady state but, instead, will evolve into an oscillatory state (limit cycle); he also demonstrated that, when the number of possible reactions is large (as in polymerization), a large number of possible steady states could exist making the product crucially dependent on the start-up and control strategies of the process.

Neal's very first collaborator on this subject was Oleg Bilous, a graduate student in chemical engineering from France who already had another advisor (Piret) as well as a formal thesis on a different topic but who, in his spare time, convincingly demonstrated theoretically the existence of such multiple steady-states. This he achieved by solving numerically the corresponding equations on a very primitive Reeves

Analog Computer which also allowed him to depict the results graphically. Subsequently, Neal was assisted over the years by a large number of exceptional students among whom Roger Schmitz, Doraiswami Ramkrishna, Dan Luss, and Arvind Varma deserve special mention because they stayed in the field and helped propagate Neal's legacy in reaction engineering. But Neal's closest collaborator from 1956 until the early 1990's was Rutherford Aris with whom he co-authored a couple of dozen papers, many of them highly cited and influential, primarily in reaction engineering but also in other areas of mathematics applied to problems in chemical engineering. Aris, born in the UK, was one of these rare and remarkable individuals, who became an outstanding applied mathematician as well as a linguist, especially in Latin and Ancient Greek, in spite of being essentially self-taught (he attended Imperial College, London, but only part time or by correspondence and received all his degrees by passing the exams). At the age of 17, Aris joined ICI as a laboratory technician in the Department of Mechanical Engineering of its research laboratory where, after being promoted about seven years later to technical officer, he started working on chromatography and on his famous Royal Society article (published in 1956) "On the Dispersion of a Solute in a Fluid Flowing Through a Tube" in which he extended the results of a landmark paper by G. I. Taylor by applying the method of moments. Shortly thereafter, Aris was transferred to a different division where he began to study the design of chemical reactors, so that, when Amundson visited the ICI Research Laboratory in 1955 during his sabbatical in the UK (see below), he and Aris met and found out that they had a great deal in common. So it came to pass that Aris, who, at the time, had only a B.S. degree, was offered a research fellowship at UM to which, after a two-year stint at the University of Edinburgh, he returned permanently as a member of the chemical engineering faculty.

DEPARTMENT HEAD AND EDITOR

Amundson became head of chemical engineering at UM in 1951. At first, nothing much happened in the department aside from some minor changes in the curriculum and the addition to the faculty of Herb Isbin, an expert in nuclear engineering. Three years later Neal took a sabbatical leave and, thanks to a fellowship from the Guggenheim Foundation, traveled to Europe, spending the major part of the 1954-55 academic year at Cambridge University with Denbigh as his host. This sabbatical turned out to be a wonderful experience for Neal, which just as was the case with his stay at Brown University ten years earlier, had far reaching implications for the development of his career because, in the mid-fifties, the Chemical Engineering Department at Cambridge included among its faculty a remarkable number of truly outstanding academics who later dispersed throughout the UK to jump-start a host of other departments of international stature. The department was led by Terence Fox who is still remembered at Cambridge for having received, as an undergraduate, not only a starred first but also all the prizes then available. Worth mentioning in parenthesis is that, throughout his career, Fox: (a) never published a single paper; (b) was a scholar rather than an innovator and very much of a perfectionist; (c) pioneered the teaching of science to chemical engineers much as Neal later did in the US (see below). During the 50's, in addition to Fox, the department included Kenneth Denbigh, Peter Danckwerts, John Davidson, and Ernest Sellars, all of whom were intellectuals of the very first rank. Thus, once again, Neal found himself in the midst of an exciting intellectual environment where provocative scientific ideas were bandied around among the members of the faculty and where the contents of the (primarily undergraduate) courses being taught were of the highest scientific caliber. On his return to UM, Neal was inspired, therefore, to try to transform his department into the model he saw at Cambridge.

But first, he needed the cooperation of his colleagues. Piret eventually resigned his professorship in order to embark on a successful and satisfying career as Scientific Attaché to the American Embassy in Paris, following which he became a high level administrator at the American Chemical Society,

Amundson portrait, 1961.
Photograph courtesy of University Archives, University of Minnesota, Twin Cities.

while George Preckshot left to become chair of chemical engineering at the University of Missouri. These departures created openings which, together with new faculty lines provided by Dean Spilhaus, enabled Neal to hire, “I never hired anybody if I thought that I was smarter than they were.”

over a ten-year period (1955-65), a roster of talented and motivated assistant professors with outstanding academic credentials using the criterion that, as he was fond of saying, “I never hired anybody if I thought that I was smarter than they were.” This group consisted of, in addition to Aris, (in alphabetical order) Bob Carr, Ted Davis, John Dahler, Arnie Fredickson, Ken Keller, Bill Ranz, Lanny Schmidt, L.E.“Skip” Scriven and Henry Tsuchiya, all of whom became internationally recognized in their respective fields. What was unusual about this group was that, although some of them had received their PhD’s in traditional chemical engineering departments, others were “from outside the box.” Carr, Davis, Dahler and Schmidt were chemists, whereas Tsuchiya and Keller had backgrounds in biochemical and biomedical engineering, respectively. But, what really made the department so successful and so unique was that, under Neal’s leadership, these new hires were able to work together, cooperate, co-supervise graduate students and even team-teach the courses of the core curriculum in spite of the wide disparity in their individual backgrounds and scientific interests. This created an exceptional spirit of togetherness and was responsible, in large measure, for the recognition of the UM Chemical Engineering Department as a top institution. Another important measure of Neal’s achievement as chair was his installation of an exceptionally loyal team environment in the department. With only two exceptions among those who were hired later, his colleagues routinely rejected the many offers they received from other institutions and refused to be enticed away.

During that time, Neal also became the editor for papers originating in the US of *Chemical Engineering Science* (CES) which had been established in the UK in 1952 under Danckwerts’s overall editorship. Neal quickly established a reputation as an effective and supportive editor, so that the journal became exceptionally influential the world over and the place to which a substantial fraction of science oriented chemical engineering researchers in the US tried to have their often highly mathematical papers published. Neal also became the editor of the Prentice Hall Series in Chemical Engineering where a large number of influential textbooks and monographs were published.

THE ADDITION OF “MATERIALS SCIENCE AND ENGINEERING” TO THE TITLE OF THE CHEMICAL ENGINEERING DEPARTMENT

From around 1880 until about 1950, the mines in Minnesota’s Iron Range (in the Northern part of Minnesota, known locally as the “icebox of the nation”) were both the main source of the US’s iron ore and a source of a significant portion of the state’s budget. This meant that programs with the title mining and metallurgy were popular not only among the students but also among UM administrators and Minnesota legislators. The School of Mineral and Metallurgical Engineering opened its doors in 1892 and eventually offered degrees in mining, metallurgical, geological, and petroleum Engineering. But, in due time, the mines were used up and university degrees with the words "mining" and/or "metallurgy" in them lost their luster not only in Minnesota but throughout the US; hence, the UM School of Mines fell on hard times with a dwindling enrollment and dwindling institutional support. This state of affairs led Warren Cheston, the dean of the Institute of Technology, to take an in-depth look at the function of the School of Mines, and to propose that the school be disbanded, with part of the faculty (specifically those in metallurgy which, in keeping with the modern times, had been renamed materials science) joining chemical engineering and the rest being absorbed by UM's Department of Civil and Environmental Engineering. Not surprisingly, the dean's proposal was treated with a distinct lack of enthusiasm by most everybody who was affected but especially so by Neal who fretted that the very unique department he had created would be diluted by the addition of outsiders, whom he had not selected personally, who might not share his vision and who might not integrate. The dean persisted, however, and offered as inducements (bribes?) most of the space of a recently constructed mines and metallurgy building that could be connected to what is now the Amundson Hall of Chemical Engineering, plus the addition of several faculty lines in polymeric materials. This last inducement seemed to have done the trick because Neal realized eventually that the addition of new faculty in polymer science and polymer processing would mesh together the existing programs in chemical engineering and in materials science. Then, as he had done earlier with chemical engineering, Neal went on to hire an exceptional team of new faculty, e.g. Macosko, E.W. Thomas, Gerberich, and Stephanopoulos whom, in standard Amundson fashion, he integrated into the existing faculty which now included the material scientists. Today, materials science and engineering represents an essential and powerful part of the combined and fully integrated department so that, following a fairly protracted induction period (ca. 30 years), most of it following Neal's move to Houston (see below), the opportunities presented by the merger have now been realized.

AT THE UNIVERSITY OF HOUSTON (UH)

In 1974 Neal decided to pass the torch to the younger generation and resigned as chairman in order to devote more time to the activities he cherished the most, teaching and research. At that time, he and Ewald Wicke in Munster, Germany, were performing complementary research on the dynamic behavior of packed-bed reactors so that, when Neal took a sabbatical leave from UM for one semester in 1975, it was natural that he spend it at the Munster Institute. Subsequently, Neal accepted an invitation from his former student, Dan Luss, to come to UH for 1.5 months to conduct research and interact with the Houston faculty. At some point during that visit, while having dinner together, Dan asked Neal if he had ever considered moving to another university. Neal responded, "I never did, and I most probably will never do it. However, if I consider it, I'll let you know." A few months later, Neal surprised Dan with a phone call, saying "Dan, you said that you would be able to get me an offer any day. Let's see if you can do it." To Neal's surprise, he got an official offer for a position at UH -- signed by the UH president -- within 36 hours of his phone call to Dan. Neal considered for about a week and then told Dan that he would accept the offer. When Neal informed the UM faculty, they were astonished and tried to keep him from leaving. Neal accepted a compromise: he would not resign from UM, but would teach at UH as a visiting faculty member during the Fall 1976 semester, return to UM for the rest of the academic year and then make up his mind what to do. Neal honored this arrangement and decided, in spite of UM's best efforts, to join the much less established UH's Chemical Engineering Department in the fall of 1977. It goes without saying that, considering Neal was universally acknowledged to be one of the most prominent chemical engineering educators and researchers in the US, his leaving UM and joining UH sent shock waves throughout the chemical engineering academic community.

A DEPARTMENTAL AND UNIVERSITY CITIZEN

At the University of Houston, Neal provided advice and guidance in recruiting new faculty members and establishing departmental policies and his presence led to a major boost in faculty morale as well as in the reputation and visibility of UH's chemical engineering program. The program vaulted into the top-ten among all US doctoral programs as evaluated by the NRC in 1982. Many distinguished professors came to visit Neal in Houston with Andreas Acrivos being the most frequent guest. Starting with Neal's 65th birthday, the department began celebrating his birthday every 5 years with a symposium and dinner that attracted many out-of-state colleagues and friends, in addition to distinguished lecturers.

Neal's influence was not limited to UH's Chemical Engineering Department. He served on many important University committees, and chaired the search committees that recruited chairs of other UH engineering departments. In 1987, he agreed to serve as interim UH Provost and, in 1988, he served as the Vice-President of Computing and Information Technology. He also had a very strong impact on the development of the

Neal Amundson, 2nd from left, with (from left) Andreas Acrivos, Rutherford Aris, Dan Luss, and L. E. Scriven at a University of Houston Conference in honor of Amundson's 65th birthday.

UH Mathematics Department, to which he was jointly appointed in 1982.

Neal went to lunch every day with most of the chemical engineering faculty and led the discussions on handling departmental problems and plans. These group lunches resulted in the rapid resolution of most issues and eliminated the need for frequent departmental meetings. Neal held strong opinions about most academic issues which he volunteered to the group and firmly believed that the success of an educator should be judged mainly by the number of successful students that he/she mentored and not just by the research that the educator and his/her students conducted given that, as he was often fond of saying, we would not be in this business without the students. He offered advice to young faculty members on becoming effective teachers, including the importance of presenting material that was not included in the prescribed textbook. Neal was a genuine "University Citizen" who placed the benefit and interests of the university well ahead of his own, the department, or the College of Engineering and he continually tried to instill this attitude in his colleagues.

RESEARCH AT UH

Most of Neal's research at UH was directed at studying the gasification and combustion of char particles and the performance of reactors in which these reactions occur. His interest in this subject was initiated by the Arab oil embargo in the 1970s, which motivated studies of synthetic fuel production from coal. Neal and his coworkers developed and analyzed single-particle models that accounted for pore-structure evolution, species and energy transport, and reaction. They also performed detailed computations to sort out the multiplicity and complex dynamics occurring at the single-particle level, in fluidized beds, and in countercurrent gasifiers. Their analyses constituted the profession's most comprehensive studies of non-catalytic gas-solid reactions, thereby providing a framework for understanding and modeling reactions involving coal char. At UH, Neal supervised the research of 17 doctoral students and several postdoctoral fellows, and published more than 40 papers on these topics.

Concurrently, influenced by his then-UH colleague Roy Jackson, Neal became interested in applying to chemical engineering problems, the Stefan-Maxwell relations, the intricate inversion of which generally requires numerical calculations to gain quantitative insights into the behavior of such systems. More specifically, Neal sought to find a simple solution for these relations as applied to the common case of mixtures with a large number of species and discovered the solution when the species were non-reacting. He presented his results in a paper published in 2003, his last publication in a chemical engineering journal. Among other findings, he showed that as the number of species is increased, the species profiles approach straight lines and, as was typical of Neal, he extended the discrete species analysis to the continuous distribution of species, enabling him to provide a theoretical and mathematical justification for this generalization.

Neal's pioneering application of modern applied mathematical tools had a strong impact on chemical engineering practice, research and education. At UH, he established collaborative research programs with several colleagues at UM and elsewhere. He also maintained his earlier extensive collaboration with his UM colleague Rutherford Aris and his former student Hyun-Ku Rhee, which led to important insights into the theory and application of first-order and quasi-linear differential equations. These contributions culminated in the publication (by Prentice Hall) of two monographs on that subject, the first volume in 1986 and the second in 1989, that are widely considered to constitute the most exhaustive treatment of this subject. Neal also had a long, close interaction with his former student Doraiswamy Ramkrishna of Purdue University. They exchanged visits—spending hours at each other's homes—and produced a book on *Linear Operator Methods in Chemical Engineering* (Prentice Hall, 1985). In 2004, the pair contributed a perspective to the *AIChE Journal*, "Mathematics in Chemical Engineering: A Fifty-Year Introspection," in which they discussed the growth of applied mathematics in chemical engineering.

More than a decade before his death, Neal recognized the importance of establishing a UH research program on air pollution. He was one of the chief principal investigators in a multimillion-dollar air quality control grant, awarded to UH in 2003, involving researchers from the mathematics, chemistry and geosciences departments and the college of engineering. Neal recognized the mathematical nature of many problems in analyzing atmospheric pollution, and he served as mentor to several young faculty members in the UH Department of Mathematics who were studying air-quality control. He also contacted John Seinfeld of the California Institute of Technology at an early stage to discuss the role that UH might play in air-quality research. This led to a three-way collaboration between Neal, Seinfeld, and a bright young mathematician, Jiwen He, on the difficult mathematical problem of predicting the thermodynamic and phase behavior of atmospheric aerosols. The result was a new thermodynamic model of atmospheric aerosols that was the first to predict the complex phase behavior of inorganic and organic atmospheric aerosols.

THE 1988 NRC REPORT ON FRONTIERS IN CHEMICAL ENGINEERING: RESEARCH NEEDS AND OPPORTUNITIES (this section by James Wei of Princeton)

What were the research needs and opportunities for chemical engineering in 1986? A study was organized under the National Research Council, and there was no one more qualified than Neal to be chosen as the chairman of the committee. His main tasks were to select the highest impact new areas to be studied, to recruit the leaders and the members who were authorities in these areas, to charge them with the tasks ahead, to organize their findings into a coherent and comprehensive report, and to set the research agenda. He was the leader to show us the way. The members of the committee were all outstanding personalities used to doing things their own ways, but they respected Neal's leadership and worked exceedingly well together. Neal recruited James Wei (then at MIT) to be the vice chairman of the committee, responsible for scheduling the work and setting the timetable, while he concentrated on the policy work of overview and external relations. The report "Frontiers in Chemical Engineering" was introduced to the world in 1988, during a symposium with outstanding speakers from academia, industry and government.

Where was the frontier? Why should we go there? How do you get there? The report said that the frontier is in new products and materials from biotechnology, electronics, and high performance materials; and the response is to generate new technologies. The frontier is in the need to lower costs and improve quality in current technologies in order to meet world competition; and the response is to sustain these industries by the development of new energy sources as well as new resources, and to improve safety and the environment. The frontier is in the intellectual curiosity of chemical engineers to gain new knowledge and tools, in computer-aided engineering and in surface sciences. The report recommended that academic departments should enlarge their horizons by offering opportunities for performing academic research in these new frontier areas, industries should expand their development and manufacturing efforts in these new frontier areas, government should increase funding research in these new frontier areas, and professional societies should promote these new frontier areas.

Neal was gratified in the following years by the number of leading chemical engineering departments that have adopted these recommendations, by appointing and promoting new faculty in these new areas. The NRC report also encouraged young students and researchers to make advances in these new frontier areas. A measure of his leadership and his vision is that, 24 years later, these new hot research areas in 2012 are still: nano, bio, energy, and environment!

NEAL THE TEACHER AT UH

At UH, Neal taught the graduate chemical engineering mathematics course, that he had developed and taught for many years at UM. He spent substantial time preparing for these lectures, and, as was the case at UM when he had started teaching decades earlier, used no notes even when covering very complicated and advanced mathematical theorems and techniques. To his colleagues' surprise, he did not keep copies of either the lectures or the original problems that he assigned or of their solutions. Every year, he produced a new set of problems and solutions. In addition to teaching mathematics, he considered it his role as an educator to advise students on how to learn any subject. He told each class, "In a course of any subject, it will not be possible for the student to understand or to follow all of the arguments instantaneously all of the time. Because your class notes will normally be very sketchy, you must expand them as soon as possible after the lecture." He pointed out to his classes:

> In science and mathematics, one must learn (memorize) and put that knowledge in the bank from which one can withdraw later. If nothing is ever put in the bank, then one is intellectually bankrupt. Most new ideas and concepts are generated by modifying existing concepts or finding connections between them. All knowledge is what one knows. If one cannot verbalize what he knows, then he probably does not understand what he thinks he knows.

In the spring of 1992, Neal concluded that it had become too difficult for him to teach the graduate chemical engineering mathematics course in accordance with his self-imposed standards and style, so he shifted to teaching required mathematics courses to undergraduate engineering students. Neal stopped teaching formal courses in 2000, but he continued to come to his UH office almost every day until 2009.

AT THE UH MATHEMATICS DEPARTMENT

Before Neal joined UH, the main research efforts in the UH Mathematics Department had been in pure mathematics, with very little activity in applied mathematics. In view of this, the College of Engineering considered starting another mathematics department that would provide the needed applied-type mathematics courses and participate in joint research activity. But shortly after Neal joined UH, he was asked by the department, the UH provost, and the UH president for advice about whether to start a mathematics department in engineering. Neal recommended not to do it (perhaps Neal made this recommendation because, as Mort Denn reminded the authors, when he had been asked many years earlier by the UM administration for advice on whether to continue the then-existing arrangement of having two math departments or whether to combine them, Neal strongly argued in favor of having a single department of which he served as interim head for about a year). From that time on, he helped the UH Mathematics Department develop interactive research programs with strengths that would support the engineering and sciences faculties and courses that would provide adequate applied training to students.

Neal regularly advised the mathematics department on what applied topics should be strengthened and what faculty should be recruited. Through Neal's extensive network of contacts, the department was able to invite top-flight applied mathematicians for seminars and extended visits. In addition, Neal served on (and often chaired) faculty search committees that hired nationally and internationally known applied mathematicians. Neal accepted a joint appointment with the UH Department of Mathematics in 1982 and contributed to a variety of departmental activities, such as developing research seminars, writing joint research proposals and conducting joint research. In the 1992-1993 academic year, Neal began teaching undergraduate mathematics courses and his willingness to teach large sections of freshman and sophomore calculus courses made a substantial impression on the entire faculty. After Neal stopped teaching formal courses, he continued for several years to conduct research with senior and graduate students, and one of his most important contributions in his later years was the mentoring of young faculty in the Mathematics Department.

NATIONAL AND INTERNATIONAL RENOWN

Neal's contributions earned him numerous professional awards while he was at UM. After joining UH, he continued to earn major awards, such as the prestigious National Academy of Engineering Founders Award (1990), election as a member of the National Academy of Sciences (1992), and fellowship in the American Academy of Arts and

From left, Neal Amundson, Shirley Amundson, Juana Acrivos and Andreas Acrivos.

Sciences (1992). The chemical engineering building at UM, his alma mater was named in his honor. The International Symposia on Chemical Reaction Engineering (ISCRE) named their award for excellence after him. He was the first recipient of the Farfel Award, the highest faculty honor conferred by UH. He also received honorary doctoral degrees from UM, the University of Notre Dame, the University of Pennsylvania, Northwestern University, and the University of Guadalajara in Mexico.

During Neal's tenure at UH, he also spearheaded an interaction with the Chemical Engineering Department of the University of Guadalajara. After presenting an invited seminar there, Neal developed a firm commitment to strengthen that academic program and, together with his wife Shirley, visited the department on a regular basis. In order to have closer contact with the students of the University of Guadalajara, Neal studied Spanish at UH and was eventually able to deliver lectures in Spanish. The University of Guadalajara recognized his contributions by awarding him an honorary doctoral degree in 1994 and also establishing a special Amundson Lecture series to which several distinguished US researchers were invited over the years.

NEAL THE HOBBYIST

Neal had several hobbies, but the one to which he devoted more time and effort than any other, was his collection of orchids which he kept in a 600-square-foot greenhouse. He started this orchid collection while he was at UM and whenever he attended a technical meeting, he devoted several hours of personal time to visiting a nearby orchid collector or a commercial grower, in order to obtain new species. When he moved to UH, he did not trust any commercial mover to take proper care of his large collection of orchids. He rented a U-Haul trailer and personally transported them from

Minnesota to Texas. He was a very active member of the Houston Orchid Society and served for a year as president of that group.

Neal Russell Amundson passed away in Houston, TX, of heart failure one month and six days following his 95th birthday. He is survived by Shirley Dimond Amundson, his wife of 70 years, their sons Gregg Russell and Erik Neal Amundson, their daughter Beth Eva Hadland, six grandchildren and four great-grandchildren. It would be difficult to imagine that anybody could have had a more meaningful and satisfying life and career.

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Awards

1958 Institute Lecturer, AIChE

1960 E. V. Murphy Award in Industrial and Engineering Chemistry, ACS

1970 Elected to the US National Academy of Engineering (NAE)

1971 W. K. Lewis Award for ChE Education, AIChE

1973 R. H. Wilhelm Award in Chemical Reaction Engineering, AIChE

1985 Founders Award, AIChE

1990 Founders Award, NAE

1992 Elected to the US National Academy of Sciences (NAS)

1992 Elected Fellow, American Academy of Arts and Sciences

Honorary Degrees

1985 University of Minnesota

1993 University of Pennsylvania

1994 University of Guadalajara

1997 Northwestern University

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