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Biography of James R. Rice

James Robert Rice (JRR) was born on 3 December 1940 in Frederick, Maryland to Donald Blessing Rice and Mary Celia (Santangelo) Rice. Located some 50 miles northwest of the nation's capital, Frederick was then a small city of about 20,000 people, set in a rural, farming area. Commemorated in Whittier's poem about Dame Barbara Fritchie's patriotism, Frederick was a crossroads for troop movements during the Civil War (1861-1865) and the birthplace of Francis Scott Key who wrote the American National Anthem. JRR's mother Mary was the child of a Sicilian immigrant family and now resides in Adamstown, Maryland. The family of JRR's father, Donald, had long lived in that part of the USA. Donald, who died in 1987, operated a gasoline station, served 3 terms as alderman and a term as mayor of Frederick City in the early 1950s, later founded a successful tire company, and, like Mary, was highly active in Frederick community affairs.

JRR was raised in Frederick, and was the second of three children. His older brother, Donald Blessing Rice Jr., served as corporate CEO of several companies (such as the RAND Corporation) in the private sector and one term as Secretary of the U.S. Air Force under the Bush Administration. He now resides in Los Angeles. JRR's younger brother, Kenneth Walter Rice, continues to live in Frederick and runs the business started by his father.

JRR attended primary and secondary school at St. John's Literary Institute, a local parish school in Frederick. He played baseball and basketball, worked part-time delivering newspapers and in his father's businesses, and read a lot. Influenced by his high school teachers of math and physics, recruited from Fort Dieterich, a local army base, JRR's early interest in auto mechanics gradually evolved into an interest in mechanical engineering. Armed with several scholarships, he began undergraduate studies in that subject at Lehigh University in Bethlehem, PA, in 1958, one year after the launch of Sputnik propelled the U.S. into a keen competition in outer space with the then-USSR.

During his undergraduate studies at Lehigh, JRR realized his particular interest was in theoretical mechanics, especially fluid and solid mechanics, and applied mathematics. Under the influence of inspiring teachers including Ferdinand Beer, Fazil Erdogan, Paul Paris, Jerzy Owczarek, George Sih, and Gerry Smith, he did his subsequent studies in the engineering mechanics and applied mechanics programs. Paul Paris has said that for the courses JRR took from him, half of Paul's preparation for each lecture consisted of answering the questions JRR had posed during the previous class meeting. Because of his proficiency in math and physics, JRR earned all his academic degrees, from B.S. to Ph.D in only six years (1958-1964), the shortest time in Lehigh's record. Ferdinand Beer directed JRR's M.S. and Ph.D. theses on stochastic processes, specifically on the statistics of highly correlated noise. The results were summarized in 1964 in his Ph.D. thesis, entitled "Theoretical Prediction of Some Statistical

Characteristics of Random Loadings Relevant to Fatigue and Fracture". At the same time, he continued working with George Sih on the subject of his undergraduate research project, elastic stress analysis of cracks along a bi-material interface. He independently developed a simple elastic-plastic crack model, which turned out to be the same as D. S. Dugdale had already published, and then extended the model to the case of cyclic loads. His work on "The Mechanics of Crack Tip Deformation and Extension by Fatigue" was published in ASTM STP 415 in 1967, and was awarded the ASTM Charles B. Dudley Medal in 1969.

In the late 1950s, fracture mechanics was still in the early stages of development. Egon Orowan of MIT and George Irwin of Naval Research Laboratory were beginning to advocate using stress analysis of cracks to solve fracture and fatigue problems in conventional metals and metal alloys. Motivated by the problems encountered while working at Boeing in the summers, Paul Paris was especially keen to work in this field. Together Paris, George Sih and Erdogan offered the *first* graduate course on fracture mechanics, which JRR took in his senior year. In addition, they recruited bright graduate students, including JRR, to do thesis research in this area. This environment cultivated JRR's interest in fracture mechanics, which became a major focus of his teaching and research.

After JRR's graduation from Lehigh in 1964, his advisor, Ferdinand Beer, suggested he accept an offer from Daniel C. Drucker to be a post-doctoral research fellow in the Solid Mechanics Group of the Division of Engineering at Brown University. Brown was (and still is) well known internationally in the solid mechanics community. At that time many world-renowned researchers in solid mechanics were members of the faculty. They included, among others, Daniel C. Drucker, Morton E. Gurtin, Harry Kolsky, Joseph Kestin, Alan C. Pipkin, Ronald S. Rivlin, Richard T. Shield, and Paul S. Symonds.

At Brown, JRR, armed with enthusiasm, energy, and innovative ideas, pursued his research on many critical fronts in fracture mechanics. He continued to collaborate with his former professors on the unfinished work from Lehigh, including characterization of fatigue loadings, plastic yielding at a crack tip and stress analysis of cracks and notches in elastic and work-hardening plastic materials under longitudinal shear loading. At Lehigh, he had also obtained some results for determining energy changes due to material removal, such as cracking or cavitation, in a linear elastic solid. At Brown, Drucker opened his eyes to the importance of generalizing these results to the widest possible class of materials; thus, JRR developed this work into a procedure for calculating energy changes in a general class of solids. This work led to JRR's discovery of the well-known J-integral a few years later. With these impressive achievements, he was offered a tenure-track faculty job as Assistant Professor in 1965.

As an assistant professor at Brown, JRR devoted his energy and efforts not only to research but also to teaching. He always believed that a good professor must excel in teaching and research. He offered many courses in applied mechanics. He developed his own lecture notes in each course without relying on specific text books. During lecturing in a typical class, he memorized every important piece of information and used the blackboard to convey the concepts to students. He was an excellent and effective communicator. Students were always welcome and encouraged to ask questions or engage in discussions. Copies of his lecture notes highlighting the key information including methods of derivations and final resulting formulae were distributed to his students.

In research, he obtained federal funding from agencies such as NSF, DARPA, NASA, ONR, and the DOE to support project initiatives on mechanics of deformation and fracture. At this time, fracture mechanics was still in the early stages of development. JRR seized the opportunity to work out many unsolved problems in stress and deformation fields around a crack in various materials systems, mostly in 2D. Some examples are: elastic-plastic mechanics of crack extension, stresses in an infinite strip containing a semi-infinite crack, plane-strain deformation near a crack in a power-law hardening material (with G.F. Rosengren), energy changes in stressed bodies due to void and crack growth (with D.C. Drucker), a path independent integral and the approximate analysis of strain concentration by notches and cracks. At the invitation of H. Liebowitz, this work was summarized in a classic review article entitled “Mathematical Analysis in the Mechanics of Fracture”, which appeared in 1968 as Chapter 3, in Volume 2, *Mathematical Fundamentals of Fracture*, of the book series, *Fracture: An Advanced Treatise*.

Of particular significance was the discovery of a path-independent integral resulting from his prior probe into energy variations due to cracking of a nonlinear elastic solid. He named this particular integral the “J-Integral” with the upper case letter “J” inadvertently coinciding with his nickname “big Jim” respectfully used by his students. This integral turned out to coincide with a 2D version of the general 3D energy momentum tensor proposed by J. D. Eshelby in England in 1956. A similar concept was also developed by Cherepanov in Russia at about the same time as Rice’s J-integral, but JRR exploited the integral’s usefulness more fully in fracture analysis, especially by focusing on aspects relating to path-independence. Because of its path independence, the J-integral is a powerful tool to evaluate energy release due to cracking, bypassing the difficulties arising from strain concentration at the crack-tip. Using the procedure he developed with Drucker, JRR showed that the J-Integral is identical to the rate of reduction of potential energy with respect to crack extension. In addition, JRR, together with the late Göran F. Rosengren, showed in 1968 that the J-integral plays the role of a single unique parameter that governs the amplitude of the nonlinear deformation and stress fields inside the plastic zone near a crack tip. This result established criticality of the J-integral as a criterion for fracture even for an elastic-plastic material and made possible its use for practical engineering applications. Simultaneously, John Hutchinson at Harvard also derived a similar result. Based on their studies, the nonlinear stress distribution in the crack tip zone is now referred to as the “Huchinson-Rice-Rosengren” or “HRR” field. Over the next decade, criticality of the J-Integral was adopted as the major design criterion against failure. It is used in the ASME Pressure Vessel and Piping Design Code, and in general purpose finite element codes such as ABAQUS and ANSYS. JRR’s paper on the J-integral, which appeared in the *Journal of Applied Mechanics* in 1968, received the ASME Henry Hess Award in 1969 and has become a classic, attracting more than 1000 citations and references. The J-Integral forms an essential part of the subject matter contained in any textbook on fracture mechanics. Because of this and other contributions, JRR was promoted to Associate Professor in Engineering in 1968 and received the ASME Pi Tau Sigma Gold Medal Award for outstanding achievement in mechanical engineering within 10 years following graduation in 1971.

As Associate Professor at Brown, JRR extended his research interests from mechanics to the physics and thermodynamics aspects of fracture phenomena. He worked with his student N. Levy on the prediction of temperature rise by plastic deformation at a moving or stationary crack-tip. When applied to a set of aluminum and mild steel alloys, this work helped to explain the experimentally observed relationship between the temperature-dependent toughness and the loading rate. Other accomplishments included his work with his student Dennis Tracey on the ductile void growth in a triaxial stress field. This work clarified the mechanism of void growth under applied stress in ductile metals. The role of large crack tip geometry changes in plane strain fracture was quantified in a paper with M. Johnson. He also actively participated in the development of formulations for finite element computations. He directed Ph.D. thesis research in computational fracture mechanics by Dennis Tracey. He interacted with Pedro Marcal, a faculty colleague and the founding developer of the MARC finite element code, and with Dave Hibbitt, Marcal's graduate student and the co-developer of the ABAQUS code. Together, they developed an appropriate numerical algorithm to compute large strains and large displacements in the finite element code. This scheme has been implemented in many general purpose finite element codes such as MARC, ABAQUS and ANSYS.

With another faculty colleague, Joseph Kestin, JRR worked on the application of thermodynamics to strained solids. For example, although the chemical potential is well-defined in fluids, the proper definition in solids is not clear. A paper by Kestin and Rice helped to clarify the concept and served as a starting point to extend JRR's developing interest in high temperature fracture, namely, creep and creep rupture.

In 1970, JRR was promoted to Full Professor of Engineering. With financial support from federal funding agencies such as the National Aeronautic and Space Administration (NASA), Office of Naval Research (ONR), DARPA, National Science Foundation (NSF) and Atomic Energy Commission (AEC, the predecessor of ERDA and the Department of Energy (DOE)), he was directing a research team of 7 Ph.D. graduate students. The team participated in the Materials Research Laboratory, a large-scale, interdisciplinary research program, funded by DARPA and NSF, and in a program of the AEC Basic Energy Sciences Division directed by Joseph Gurland. JRR's students worked in a wide range of areas in the mechanics of solids and fracture: Dennis Tracey, Dave Parks, and Bob McMeeking in (1) theoretical and computational fracture mechanics; Art Gurson in (2) constitutive relationships in metals and metallic alloys; G. M. Brown and T.- j. Chuang in (3) creep and creep rupture in the high temperature range; and Mike Cleary in (4) mechanics of geomaterials. Representative work in (1) included an alternative formulation of Bueckner's (1970) weight function method to evaluate the stress intensity factor K_I of a given 2D linear elastic cracked solid subject to arbitrary loading, based on any known solution to the same geometry; a finite element analysis of small scale yielding near a crack in plane-strain (with N. Levy, P.V. Marcal and W.J.Ostergren); an approximate method for analysis of a part-through surface crack in an elastic plate (with N. Levy); and 3D elastic-plastic stress analysis for fracture mechanics (with N. Levy and P. V. Marcal). In (2) JRR worked out the fundamental structure for the time-dependent stress-strain relationship of a metal in the plastic deformation range and proposed an internal variable theory for the inelastic constitutive relations in metal plasticity.

In 1971-72, JRR took a year of sabbatical leave with support from a NSF Senior Postdoctoral Fellowship. He spent the year at the Department of Applied Mathematics and Theoretical Physics of the University of Cambridge, where he was affiliated with Churchill College under the support of a Churchill College Overseas Fellowship. At Cambridge, he worked with a number of people, including Rodney Hill, one of the pioneers in classical plasticity, Andrew C. Palmer in soil mechanics, and John Knott and his student Rob Ritchie on elastic-plastic fracture. With Hill, JRR developed a general structure of inelastic constitutive relations assuming the existence of elastic potentials, and gave a special implementation for elastic/plastic crystals at finite strain. In the latter case, crystallographic slip along a set of active slip planes was considered as the sole deformation mechanism responsible for the inelastic behavior. This theory successfully explained various aspects of plasticity such as strain hardening, the existence of a flow rule and normality.

With Knott and Ritchie, JRR proposed a relationship between the critical tensile stress and the fracture toughness of mild steel. The analysis predicts the observed temperature dependence of K_{IC} over the range from -150°C to -75°C. With Andrew Palmer, JRR used his newly developed J-integral to develop a mode-II "shear crack" model for the growth of slip surfaces in over-consolidated clay slopes.

Returning to Brown in 1972, JRR continued to pursue research on many aspects of fracture mechanics. John Landes and Jim Begley of the Westinghouse R&D Center became keen advocates of using the J-Integral as a design criterion in the nuclear energy business, and in a paper with Landes and Paul Paris, JRR developed an elegantly simple procedure to estimate the value of J-Integrals from experiments. Eventually, this procedure became the ASTM standard and part of the ASME Pressure Vessels and Piping design code. Besides analysis on the continuum level, JRR strongly felt that there was a need to study fracture at the microstructural level in order to bridge the atomic and engineering scales. One important area that required such a treatment is high temperature creep and creep rupture where mass transport plays an important role. At that time, a group at Harvard led by Mike Ashby was also interested in this topic. As a result, there was much interaction between Harvard and Brown during 1972-74: JRR and Ashby and their students made frequent mutual visits to give seminars and to exchange ideas. One important result, jointly developed in 1973 with his student, T.- j. Chuang, was the discovery of creep crack-like cavity shapes induced by surface diffusion. This type of cavity, referred to as a Chuang-Rice crack-like cavity, is frequently observed at the grain boundaries of a ruptured tensile specimen. This work defines the boundary conditions at the cavity apex and satisfactorily explained non-linear stress dependence on cavity growth rate. The degree of non-linearity depends on the deformability of the grains, and JRR obtained solutions for the stress dependence on creep cavity growth in rigid grains (with Chuang, Kagawa, Sills and Sham), in elastic grains (with Chuang) and in plastic grains (with Needleman). The predicted stress dependence was verified experimentally by Bill Nix and his students at Stanford in the late 1970s, using implanted water vapor cavities at grain boundaries in pure silver and nickel-tin alloys. Later in the 1980s and 90s, this work was used by many researchers to predict cavity growth induced by electromigration in aluminum interconnect wires.

In 1973, JRR was offered a Chair by the Brown President, Donald Hornig with the title L. Herbert Ballou Professor of Theoretical and Applied Mechanics. This privileged title is an honor comparable to a University Professorship, which is the highest rank of teaching professors at Brown.

In physical metallurgy, it had become well-known that dislocations at the atomic level are fully responsible for the plastic behavior in metals. Since the early 1960s, many researchers (such as Hirth, Lothe, Mura and Weertman) devoted their efforts to this area and helped to build the foundation of dislocation theory. JRR was among those cutting edge scholars who excelled in mathematical dislocation theory. In 1972, he met Robb Thomson of SUNY-Stony Brook at a conference and they puzzled over the ductile versus brittle transition phenomenon in crystals. Since dislocation movement leads to ductility and rapid crack growth leads to catastrophic failure, they believed the interactions of both must play a dominant role in ductile/brittle behavior. They proposed that the ability to emit dislocations from a pre-existing sharp crack tip is the source of ductility in metals. On the other hand, the resistance of a crack tip against dislocation emission leads to brittleness in ionic or covalent crystals like ceramics. By analyzing the energetic forces between a dislocation and a crack, they derived an important parameter that governs the ductility. If this parameter, which is shear modulus times Burgers vector over surface energy, exceeds 8.5

to 10, then the crystal exhibits intrinsically brittle behavior. If less, it is generally ductile. The Rice Thomson theory has become a classic in the Science Citation Index with more than 200 citations. In the late 1970's, Mike Ohr of Oak Ridge National Laboratory provided direct experimental evidence for the theory by observing emission of dislocations from the crack tip in a variety of metal specimens ***in situ*** under TEM.

In another noteworthy work, JRR helped his student Art Gurson to develop in 1975 the plasticity theory of porous media, in which yield criteria and flow rules were predicted in stress space using 2D or 3D unit cell models. The model predicts the effect of porosity on the plastic behavior of ductile materials and has come to be known as the "Gurson" model. It is well-known in the metallurgy and mechanics communities and is one of the major yield criteria adopted in the commercial general purpose finite element codes for assessing inelastic behavior of metallic materials.

Motivated by his studies of shear bands with Andrew Palmer, JRR became interested in the fundamental question of why deformation would localize in a narrow zone. A basic premise of fracture mechanics, going back to the ideas of Griffith, is that the presence of flaws in a material causes a local elevation of the stress and leads to propagation of the flaw and, eventually, to failure. Although this process provides a satisfactory explanation of failure in many materials, it does not explain why macroscopically uniform deformation should give way to localized deformation in very ductile materials or under conditions of compressive stress that suppress flaw propagation. Based on antecedents in the work of Hadamard, Hill, Thomas and Mandel, JRR and his student Rudnicki treated the initiation of localized deformation as a bifurcation from homogeneous deformation and showed that its onset was promoted by certain subtle features of the constitutive behavior. This work, which was published in the *Journal of the Mechanics and Physics of Solids* in 1975, received the Award for Outstanding Research in Rock Mechanics from the U. S. National Committee on Rock Mechanics in 1977. Although this work was originally intended to describe fault formation in rock, JRR extended the approach to consider localized necking in thin sheets (with S. Storen), strain localization in ductile single crystals (with R. J. Asaro), and limits to ductility in sheet metal forming (with A. Needleman). He summarized the state of the subject in a keynote lecture on "The Localization of Plastic Deformation" at the 14th International Congress on Theoretical and Applied Mechanics in Delft in 1976. The printed version of this lecture is a widely-cited classic.

In the early 1970's, there were many reports of observations precursory to earthquakes that were attributed to the coupling of deformation with the diffusion of pore fluid. A series of papers, by JRR with students (Cleary and Rudnicki) and Don Simons, an Assistant Professor at Brown, analyzed the effects of this coupling on models for earthquake instability and for quasi-statically propagating creep events. One of these papers ("Some basic stress-diffusion solutions for fluid-saturated elastic porous media with compressible constituents", with M. P. Cleary, *Rev. Geophys. Space Phys.*, 14, pp. 227-241, 1976) reformulated, in a particularly insightful way, the equations first derived by Biot for a linear elastic, porous, fluid-infiltrated solid. This version of the equations has proven so advantageous that it is now the standard form. The models of the earthquake instability formulated to study these effects were among the first in which the instability was not postulated but arose in a mechanically consistent way from the interaction of the fault zone material behavior and the surroundings.

JRR's interest in the mechanics of earthquakes proved durable and became a major branch of his work. With Florian Lehner and Victor Li, he worked on time-dependent effects due to coupling of the shallow, elastic portion of the Earth's lithosphere with deeper viscoelastic portions. This work was based on a generalization of an earlier thin plate model by Elsasser. This work demonstrated that the viscous deformation of the lower crust and upper mantle following large earthquakes could affect surface deformation for decades and provided a new model for the interpretation of increasingly detailed surface deformation measurements. JRR's growing interest in the mechanics of earthquakes complemented nicely the interests of his spouse, Renata Dmowska, a seismologist. Together, Renata's analysis of data and JRR's mathematical models have been combined in several papers on aspects of earthquakes, particularly in subduction zones.

JRR's interest in the mechanics of earthquakes soon led to a study of frictional stability. Stick-slip is a widely observed phenomenon and has long been regarded as a physical analog for the earthquake instability. But the standard constitutive description, static and dynamic friction, was inconsistent with the steady sliding often observed and contained no mechanism for restrengthening that would allow repeated events on the same surface. Based on experimental observations of Dieterich at the U.S. Geological Survey, JRR and his student Andy Ruina formulated a rate- and state-dependent constitutive relationship for sliding on a frictional surface. By examining the stability of a one degree-of-freedom system with this relationship, they were able to predict the variety of behaviors observed in rock friction experiments: steady sliding, damped oscillations, stick-slip and sustained periodic oscillations. Other papers with Tse and Gu examined the dynamics and nonlinear stability of these systems. JRR and his student Tse showed that when this type of relationship was applied on a surface between two elastic solids and modified to include a depth dependence appropriate for the temperature and pressure dependence in the earth,, the calculations produced periodic events with a depth dependence remarkably similar to that of observed earthquakes.

In the late 1970s and early 1980s, JRR also continued to work on many aspects of inelasticity and fracture. With Joop Nagtegaal and Dave Parks, he developed a numerical scheme to improve the accuracy of finite element computations in the fully plastic range With Bob McMeeking, he worked out the proper finite element formulation in the large elastic-plastic deformation regime. With a colleague at Brown, Ben Freund, and a student, Dave Parks, he helped solve the problem of a running crack in a pressurized pipeline. In materials science, he studied stress corrosion and hydrogen embrittlement problems.

He also orchestrated a remarkable multidirectional attack on the problem of quasi-static crack growth in elastic-plastic materials. This began with a theory paper with Paul Sorensen in 1978 that proposed an elegant way of using near-tip elastic-plastic fields to derive theoretical predictions for crack growth resistance curves (J_R curves). Then, he and his student Walt Drugan derived asymptotic analytical elastic-ideally plastic solutions for the stress and deformation fields near a plane strain growing crack which showed the necessity of an elastic unloading sector in the near-tip field. [Independent work by L. I. Slepyan in the then-USSR and Y. C. Gao in China also addressed this problem, for incompressible material and steady-state conditions.] The detailed numerical finite element elastic-plastic growing crack solutions of JRR's student T-L. Sham confirmed the analytical predictions, and in a 1980 paper with Drugan and Sham, JRR combined the method proposed earlier with Sorensen, with the new analytical asymptotic solutions and Sham's numerical results, to produce a comprehensive and fundamentals-based model of stable ductile crack growth and predictions of plane strain crack growth resistance curves. Then, with Lawrence Hermann, JRR conducted and analyzed "plane strain" crack growth tests and showed that this theory was indeed capable of describing the experimentally-measured crack growth resistance curves under contained yielding conditions.

The asymptotic analysis of elastic-ideally plastic growing crack fields, involving the assembling of different possible types of near-tip solution sectors into complete near-tip solutions, prompted JRR and Drugan to inquire more fundamentally about what continuity and jump conditions are required across quasi-statically propagating surfaces in elastic-plastic materials by the fundamental laws of continuum mechanics and broad, realistic constitutive constraints (such as the maximum plastic work inequality). Their resulting restrictions (published in the D. C. Drucker Anniversary Volume), and the later generalization of these to dynamic conditions by Drugan and Shen, have been utilized repeatedly in elastic-plastic crack growth studies. Not surprisingly, perhaps the most important applications of these discontinuity results are due to JRR himself, in his fundamental studies of stationary and growing crack fields in ductile single crystals, wherein JRR showed that a precise understanding of possible discontinuity types is absolutely essential in deriving correct solutions. Beginning in 1985 with his student R. Nikolic on the anti-plane shear crack problem, and in a landmark, pioneering 1987 paper on plane strain tensile cracks, JRR produced fascinating analytical solutions for the near-tip fields in elastic-ideally plastic ductile single crystals. These fields differ dramatically from crack fields in isotropic (i.e., polycrystalline) ductile materials, being characterized by discontinuous displacements and stresses for stationary cracks, discontinuous velocities for quasi-statically growing cracks, and, in another fascinating paper with Nikolic in 1988, JRR showed that the near-tip field for a dynamically propagating anti-plane shear crack in a ductile single crystal must involve shock surfaces across which stress and velocity jump. JRR and his student M. Saeedvafa generalized the stationary crack ductile single crystal solutions to incorporate Taylor hardening, revealing even more complex near-tip behavior.

Other major work in the late 1970s and early 1980s included two important papers with visiting faculty members: one on the crack tip stress and deformation fields for a crack in a creeping solid, with Hermann Riedel; and another heavily-cited paper on crack curving and kinking in elastic materials, with Brian Cotterell.

For his significant contributions to sciences and engineering, he was elected to Fellow grade of the American Academy of Arts and Sciences in 1978, Fellow of the American Society of Mechanical Engineers and Membership in the National Academy of Engineering in 1980, and Membership in the National Academy of Sciences in 1981.

The next move was to Harvard University in September 1981. A Gordon McKay Chaired Professorship in Engineering Sciences and Geophysics was created for JRR, jointly in the Division of Applied Sciences and the Department of Earth and Planetary Sciences. He further expanded the scope of his research activities along two major branches of discipline in mechanics, namely, fracture of engineering materials and geological materials. At Harvard, he recruited many bright students from all over the world to work on topical fracture problems in engineering and geology. He directed Peter Anderson to study constrained creep cavitation and the Rice-Thomson model, supervised Huajian Gao on three dimensional crack problems, worked with Jwo Pan, Ruzica Nikolic and Maryam Saeedvafa on inelastic behaviors of cracks in single crystal metals, and collaborated with Renata Dmowska, Victor Li, Paul Segall, Andy Ruina, Yehuda Ben-Zion, G. Perrin, J.-c. Gu, Mark Linker, Simon T. Tse , G. Zheng, and F. K. Lehner in developing friction laws and shear crack models of geological faults as related to earthquake events in seismology.

JRR's recent work on earthquakes has focused on several important aspects of the process. One issue is the origin of earthquake complexity, that is, the distribution of events of various sizes, as described by the well-established Gutenberg-Richter relationship. One previous explanation was that fault slip, as modeled by friction between two elastic solids, was an inherently chaotic process. In a series of papers that combine elegant analysis and prodigious calculations, JRR and his post-doc, Yehuda Ben-Zion, showed that the chaotic behavior predicted in these models was the subtle result of numerical discretization and oversimplification of the frictional constitutive relation. Other work was motivated by observations that slip during an earthquake does not propagate in the fashion predicted by classical dynamic fracture mechanics with most of the surface slipping for the entire duration of the event. Instead, slip is pulse-like and any point on the surface slips only for a short time. Papers with Zheng and Perrin showed that only certain types of frictional constitutive relations were consistent with these observations. Another, very influential paper, "Fault Stress States, Pore pressure Distributions and the Weakness of the San Andreas Fault" addresses a long-standing paradox in earthquake mechanics: A variety of measurements indicate that the San Andreas fault in southern California is much weaker, both in an absolute sense and relative to the surrounding crust, than would be expected from a straightforward interpretation of laboratory friction experiments. JRR showed that the discrepancy could be resolved by high fluid pressures within the fault zone and summarized a variety of evidence for this possibility.

In the mid-1980's, JRR and other faculty members including John Hutchinson and Bernie Budiansky formed a joint research team with Tony Evans at the University of California at Santa Barbara to study mechanical behavior and toughening mechanisms of ceramics. Between 1988 and 1994, faculty and students at Harvard regularly visited and exchanged ideas with Tony Evans and his research group at UCSB. The Harvard-UCSB collaboration generated tremendous research output. During this period, JRR worked with John Hutchinson, Jian-Sheng Wang, Mark E. Mear and Zhigang Suo on crack growth on or near a bi-material interface. With Jian-Sheng Wang, he developed a model of interfacial embrittlement by hydrogen and solute segregation. This model has been referred to as the Rice-Wang Model which provided a basis for the materials community in pursuit of better design of steels. Between 1989 and 1995, JRR worked with Glenn Beltz, Y. Sun and L. Truskinovsky to reformulate the Rice-Thomson model in terms of interactions between a crack and a Peierls dislocation being emitted from the crack tip. This study eliminated the need to define a core cut-off radius for dislocations and instead established unstable stacking fault energy as the new physical parameter governing the intrinsic ductility of crystals. Rice's new model caused an instant sensation among materials scientists and physicists and is now used as the new paradigm for understanding brittle-ductile transition of crystals.

Separate from his other activities at Harvard, JRR began to develop a growing interest in three dimensional crack problems, starting around 1984. Together with Huajian Gao, the first of his graduate students at Harvard to work on 3-D crack problems, he developed a series of ingenious methods of analysis based on the idea of 3-D weight functions, generalizing a 2-D concept he and Hans Bueckner had developed in the early 1970's. These methods were used to study configurational stability of crack fronts, crack interaction with dislocation loops and transformation strains, and trapping of crack fronts by tough particles. In 1987, he began to work with K. S. Kim, who spent a year of sabbatical at Harvard, to generalize these methods to model dynamically propagating 3-D crack fronts. This then led to a burst of his interests in the following years in the spontaneous dynamics of 3-D tensile crack propagation and of slip ruptures in earthquake dynamics. He directed a number of graduate students, post-docs and visiting scientists on those areas, including K. S. Kim, Yehuda Ben-Zion, G. Perrin, G. Zheng, Phillipe Geubelle,

A. Cochard, J. W. Morrissey, and Nadia Lapusta. He also encouraged other leading scientists such as John Willis and Daniel Fisher to work in this field. An example of significant discoveries coming out of these activities is a new kind of wave which propagates along the crack front at a velocity different from the usual body and surface elastic wave speeds. JRR continues today to lead an international research effort in crack and fault dynamics. Needless to say, the output of his research group is of the highest quality and generates significant impact on the engineering, materials science and geophysics communities.

As a result of his contributions to science and engineering, JRR received numerous awards and recognitions by professional societies and academic institutions. In 1981, he was elected to to Fellow of AAAS. Next year in 1982, he received the George R. Irwin Medal from ASTM Committee E-24, shared with John Hutchinson, for "significant contributions to the development of nonlinear fracture mechanics". In 1985, he was one of the recipients of an Honorary Doctor of Science Degree at his alma mater, Lehigh University. In 1988, he was elected Fellow of the American Geophysical Union, and received the William Prager Medal from the Society of Engineering Science for his "outstanding achievements in solid mechanics". Two years later, he was elected Fellow of the American Academy of Mechanics and the Royal Society of Edinburgh. In 1992, he received an award from AAM for "Distinguished Service to the Field of Theoretical and Applied Mechanics". The following year he served as Francis Birch Lecturer on "Problems on Earthquake Source Mechanics" at the American Geophysics Union. The next year he received the ASME Timoshenko Medal with the following citation: "for seminal contributions to the understanding of plasticity and fracture of engineering materials and applications in the development in the computational and experimental methods of broad significance in mechanical engineering practice". In 1996, he was elected as a Foreign Member of the Royal Society of London for his work on "earthquakes and solid mechanics" and received an honorary degree from Northwestern University. In addition, he received the ASME Nadai Award for major contributions to the fundamental understanding of plastic flow and fracture processes in engineering and geophysical materials and for the invention of the J-Integral which forms the basis for the practical application of nonlinear fracture mechanics to the development of standards for the safety of structures. He also received the Francis J. Clamer Medal from the Franklin Institute for Advances in Metallurgy with the citation: "for development of the J-Integral for the accurate prediction of elastic-plastic fracture behavior in metal from easily obtained data". In 1997, he received an honorary Doctor of Science degree from Brown University. In 1998, a donation from David Hibbitt and Paul Sorensen of HKS, Inc. established the Rice Professorship at Brown in his honor. Recently, he was awarded the Blaise Pascal Professorship by the Region Ile-de-France for the 1999 calendar year for research on "Rupture Dynamics in Seismology and Materials Physics", and he was the recipient of an Honorary Doctoral Degree at the University of Paris VI in March 1999. He was elected a Foreign Member (Associé Étranger) of the French Academy of Sciences in April 2000.

There is no need to place complimentary words here on the impact of his work. The recognitions described in the previous paragraph speak for themselves. His standards of scholarship and intellectual honesty are the highest. He is always ready to appreciate the good work of other colleagues, and to give them proper credit. On the other hand, he does not hesitate to dispense candid criticism of inconsistent or misguided thinking, though in a gentle rather than harsh manner -- as some oral comments in conferences or written book reviews testify.

A man is as young as he thinks. JRR enjoys long walks, whether in urban or mountain settings, reads broadly in science, history and social commentary, and likes listening to classical and folk music in his spare time. He has an excellent sense of humor, a razor-sharp wit and a cheerful disposition. His wife Renata Dmowska, in addition to being a regular and important scientific collaborator, is an excellent influence on Jim. Renata is an enthusiastic polymath with a warm and cheerful personality and a seemingly endless array of interests. She insists that he take much-deserved breaks from his research to attend concerts, to visit art museums, to travel, to read literature, and to socialize with their large circle of friends. JRR is increasingly active in his research, full of curiosity, creativity and persistence. As his students can attest, he is also an excellent teacher in the classroom. He gives lectures in a humorous, but comprehensive way that can be easily digested by his audience. As a thesis advisor, he defines the scope of a research area in which he sees the potential for advancement. He inspires and encourages, but does not push his students. When a student heads in a wrong direction or reaches a dead end, he wastes no time to steer him or her back to the right track. His good qualities as an advisor were recognized by his recent Excellence in Mentoring Award conferred by the Graduate Student Council of Harvard University in April 1999.

JRR recently returned from his full year sabbatical leave (January 1999 to January 2000) in Paris, France, working in the Département Terre Atmosphère Océan of École Normale Supérieure, and also part time at École Polytechnique in Paliseau. His flow of publications shows no sign of diminishing and his friends and colleagues surely will hope that the short legend “J. R. Rice” will appear again and again in the scientific literature for many years to come.

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