A sketch of my life

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It was beyond my imagination that I may have to write a short sketch of my life. It is indeed a privilege to be a Fellow of an Academy that encourages doing so. I come from a family of teachers. My grandfather used to teach mathematics at colleges at Patna and Muzaffarpur in Bihar. He died in 1949 a few months after I was born. My father had a distinguished academic career. He was a Captain in the Army Medical Corps during the World War II. Later he came back to teaching. He retired as Principal, Darbhanga Medical College in North Bihar.

My early education was through private tutors at home. This was primarily because my father had to spend nearly 3years in Edinburgh during early 1950s for his doctoral degree. My mother along with me and my sister had to shuttle between our ancestral house at Rajmahal and Patna, the then state of Bihar, where my grandmothers lived. On his return my father joined Darbhanga Medical College as a professor and we moved to Laheria sarai where the college was located. I started going to school as a regular student when I was 8 year old (1956). I was admitted directly to class VI in M L Academy (Also known as Saraswati School possibly its initial name) a Hindi medium secondary school. It was established with assistance from the Maharaja of Darbhanga. Although there was a Zila school in the town, my father insisted that I should go to this school because of the reputation of Jhingur Kunwar its Head Master and Nani Gopal Chakraborty its Assistant Head Master. Both of them were highly respected teachers. I was an average student until 1961. It was possibly because of my poor eyesight. Once I started using glasses my performance started improving. This was also the year our school was upgraded to Higher Secondary. It meant on completion of school one could get a direct entry into engineering or medical colleges. Mathematics was my favorite subject. Ours was the first batch of this school to appear for the Bihar Higher Secondary Board examination held in March 1964. Our teachers in the school had great hopes,but only six of us in a class of around 80 students passed in the First Division. A few of my class mates appeared for the Joint Entrance Examination for admission to IIT held during the first weekend of May 1964. When I went to appear for the examination held at Bihar Engineering College, Patna it was a great surprise to find that Arun Pradip Sinha the topper of our class was sitting next to me. We had four papers Mathematics, English, Physics and Chemistry. Questions were of much higher standard than those we were familiar with so far. I still remember that the Mathematics paper

had 25 short questions of 1 mark each and there were negative marks for every wrong answer. Luckily I concentrated more on the remaining fifteen questions of 5 marks each. We were certainly not happy with our performance in the examination. It was a great surprise to find that both of us had qualified. Those-days successful candidates had to appear for counseling for allotment of seats in various disciplines and face medical examination in respective zonal institutes. We had to come to IIT Kharagpur and we were impressed with its sprawling campus and the facility. Students were called in batches of 60. Arun's counseling was held on the first day hewas admitted to Mechanical engineering whereas my counseling was on the following day. I had to settle for Metallurgical Engineering. In those days IIT Kharagpur used to be the first preference for most students. For a little known Hindi Medium school in a small town in North Bihar it was indeed an achievement to have two of its students qualify in such a competitive examination and get admitted to IIT Kharagpur.

My association with IIT Kharagpur formally began from the 1st of July 1964 as a first year B.Tech student of Metallurgical Engineering. Hostels in the campus were named after our National Leaders. I was a resident of Nehru Hall during my under graduate days. Barring a few months most us got single seated rooms. I preferred to stay in a double seated room during my first year along with Pobitra Majumdar a student of Naval Architecture. Those days only the double seated rooms used to have ceiling fans. For a sixteen year old boy it was tough to be away from home. It took some time to get adjusted with the new environment. The tight academic schedule and examinations held at regular intervals kept us busy. The first two years were mostly devoted to basic science and engineering courses. Every year we had to face three examinations held during September, January and April. The end term examination used to have questions from the entire course. There was also a system of open book examination on a few subjects where students were allowed to consult books during examination. Interaction with the Department of Metallurgical Engineering was minimal during the first two years. We had occasional orientation classes where we had opportunity to listen to a few faculties of our department. This is when met Prof E H Bucknall. He gave us a general overview of metallurgy. On his suggestion most us purchased a book titled Metals in the Service of Man which I still posses. It gives an excellent exposure on the extraction, processing, properties and uses of all common metals and alloys. The first three years were mainly devoted to basic courses in mathematics, physics chemistry and engineering whereas subjects related to metallurgical engineering were taught in our fourth and fifth years. My favorite subjects were metallurgical thermodynamics, X-Ray diffraction and Metal Physics. These were taught by Professor P R Dhar, Professor P G Mukunda and Prof S K Mitra respectively. I still remember having solved all the numerical problems given in the book of Metallurgical Thermodynamics by Darken & Gurry. We were also fortunate to have access to most of the laboratory facility that were available in our department.

After obtaining B.Tech degree, I joined the M.Tech program in Physical Metallurgy offered by the Department. The first year was devoted primarily to lecture and laboratory classes. The courses were a little more quantitative. Therefore I started liking the course and my performance in the class improved significantly. I was assigned a project on tempering characteristics of steel having Si as one of the intentionally added elements. This was done under the guidance of Dr R A Tewari and Professor PR Dhar. Dr Tewari around the time had just completed his PhD. His thesis was on the tempering behavior of Si steel. Professor Dhar wanted me to investigate the effect of Ni addition on transformation characteristics of this steel. One of the objectives of Ni addition was to suppress the effect of auto-tempering. The amount of Ni to be added was found to be close to 18%. The alloy was made in an air induction furnace. The alloy was amenable to both hot and cold working. It had to be quenched in liquid nitrogen for hardening. I had to design and fabricate a simple setup to measure magnetic permeability after quenching the sample to subzero temperatures so that the temperature at which the soft austenite in this steel transforms into hard martensite could be determined. On tempering the steel at

400^0C after quenching in liquid nitrogen it was found that the hardness has increased from 400VHN to 500VHN. Hardness versus ageing time plot was very much similar to that shown by age harden-able alloys. Attempts to identify the precipitate by recording X-ray diffraction pattern using Debye-Scherer camera or selected area diffraction patterns obtained during examination of extraction carbon replica or thin foils under EM6 transmission electron microscope only showed reflections that were coincident with those expected from austenite. It was found that diffraction peaks from Ni_3Si could be coincident with those from austenite. In the absence of access to SEM or TEM having EDS facility its presence could not be proved conclusively. Nevertheless it fetched me Master's degree with excellent grade. I also received the Alumni Association Gold Medal on being adjudged the best post graduate student for the session 1969-71.

I subsequently got selected for the post of lecturer at IIT Kharagpur. This gave me an opportunity to serve my alma-mater from October 1971. I took up the profession of teaching seriously. This helped me develop a clear concept on the evolution of structures in materials during processing and its effects on its performance. While going through the literatures on strengthening mechanism in metals and alloys, I came across two papers by Sandip K Mitra one of my teachers; one was with Donald McLean of NPL Teddington, UK and other with J EDorn of University of Berkley, California. Both of these were widely referred in technical papers and books. Therefore I decided to work for my PhD under his guidance. Amitabh Biswas who was two year senior to me was also working for PhD under his supervision. He had an excellent skill to setup experimental facility. He had built a unit which could grow single crystal of aluminum and a constant stress creep testing machine. We started working together as a team. Development of dispersion strengthened alloys for high temperature service was an area of considerable interest in early seventies. At high temperature all metals undergo time dependent deformation even if the stress is lower than its yield stress. This phenomenon, called creepis associated with the movement of dislocation (crystal defects). The presence of stable dispersed particles inhibits such movement. This results in the improvement of its creep resistance.I used co-precipitation technique to produce silver coated silica particles so that these could be incorporated in the metal to improve its creep resistance. It was possible to control the silver to silica ratio. However it could be melted and cast only if the amount of silica was very less. In cases where the amount of silica was very high it did not melt at all. It was possibly because the coating was too thin. There was marginal increase in hardness wherever melting and casting was possible yetthe tensile strengths in bulk of the cases were found to be lower than that of pure silver. Meanwhile I also picked up FORTRAN language to write computer programs to solve numerical problems. Those days the only facility that was available was the main frame computer. We had to write the code and submit the job in the form of a pack of punched cards. Often we had to wait for several days to get an output in the form of a print out. It used to take several months to debug and run a couple of hundred lines program. In spite of this constraint I was able to develop a model that could simulate the effect of sudden change in stress on the shape of the creep strain time plot. This technique was used by Mitra & McLean to estimate creep recovery rate. The measurement showed that at a constant temperature the recovery rate (r) is proportional to stress raised to the power of 3. The work hardening (h) was known to be inversely proportional to stress. Thus it was possible to explain why steady state creep rate which is given by the ratio r/h; is of the order of 4. Although the recovery-work hardening model could explain the creep behavior of most metals and single phase alloys it failed to account for the unusually high stress exponent found in the case of precipitation strengthened alloys. In order to explain this, the concept of effective stress which is defined as the difference between the applied stress and the internal stress that develops within the metal during deformation, had to be introduced. I used this concept for numerical simulation of the creep strain transient tests. The results showed that such tests give correct estimate of recovery rate only if the internal stress is equal to the applied stress. It was also experimentally validated. This formed

the main part of my PhD thesis. Unfortunately Professor Mitra passed away in 1979 when I was still in the midst of compiling my work. Nevertheless it resulted in several quick publications and I got my Doctorate degree in 1981.

One of the major constraints for research those days was the access to precision testing machines even in premiere institutes like IITs. In order to generate creep strain time plots to estimate work hardening and recovery rate I had to use a unit that was fabricated by us. We also had to build an emergency power supply unit to provide power to the creep tester in case of power failure. This is when I got an opportunity to visit National Metallurgical Laboratory (NML) in November 1975. I was to presentapaper atthe Annual Technical Meeting of Indian Institute of Metal which was being held in its premises. This is when I saw the newly built Creep Testing Facility at NML. It had over 200 creep test points and a centralized data collection station housed in an air conditioned hall. I was so impressed with the setup that when I got an opportunity, I readily accepted the offer to join NML.

When I came here as a scientist in December 1982 I was placed in the Creep Laboratory.This was a part of the Material Science Division. Dr Rajendra Kumar was the head of this group. Professor Altekar was the Director of the Laboratory. Those days it was extremely difficult to get family accommodationin NML campus. The problem was so acute that many had to wait for 10-15 years. I too had to suffer. The situation might have been different if I would have asked for lien terms which allowed consideration of past service for the allotment of a quarter. I missed this opportunity as I followed the advice of Dr Kumar and resigned from a permanent position at IIT on the false belief that I may be allotted a quarter out of turn. This did not happen. I had to live in a rented house in Sonari, Jamshedpur with my family for over six years. In those days getting a good private accommodation in Jamshedpur was extremely difficult. Nevertheless I learnt a lesson that apart from being a scientist one has to be more aware of rules & regulation. When I look back now I do not repent the decision I took. If I would not have done so I might have gone back to the peaceful & relaxed academic environment of IIT possibly within a year.

Initially I was associated inthe evaluation of creep resistance of indigenously produced steel so that these could be accepted for use in boilers of power plant. So far only graphical comparison of stress rupture plots of the steels under evaluation with those of the established grades was being used as the acceptance criterion. This was quite subjective in the presence of the scatter normally associated with such data. The absence of any computational aidswas a major bottleneck for the proper analysis of the huge volume of creep data that were generated in the laboratory. I had to present the work that has been done so far creep resistant steel before a meeting of Indian Creep Panel having members from Steel Plants, BHEL, Atomic Energy and Boiler Board in early 1984. Luckily this is when Professor O N Mohanty my former colleague at IIT Kharagpur had joined NML as its Deputy Director. He had a programmable calculator. This helped me analyze the data quickly and present these in a way that was appreciated by all. This is when I came to know that attempts to setup computational facility did not materialize because of stiff resistance from the employees union. Subsequently before Professor Altekar retired it was possible to buy and install two word processors which could also be used as a computer. I was given the responsibility to install, run and train those who wanted to use the system. We also developed a set of programs that could be used to predict remaining lives of service exposed high temperature components such as steam pipes from accelerated tests performed in the laboratory. Apart from creep testing I was also involved in failure analysis of oil refinery and power plant components. This gave me an opportunity to visit several power plants, oil refineries and fabrication units. The interaction with those involved in running these helped me appreciate and learn a lot about the material related problems being faced by them.

Professor S. Banerjee joined NML as its Director in December 1984. Before taking over this responsibility he did visit us on several occasions. I met him possibly in March 1983 when he came to NML on a short visit and delivered a couple of lectures on Application of Fracture Mechanics. He again came to NML during summer vacation for a little longer stay. During this period I did interact with him much more closely. We were able to initiate fatigue pre-crack in 3 point bend specimen using the then existing electro-magnetic fatigue tester (Vibrophore). The pre-cracked specimen was finally tested on 25 ton screw driven Instron testing system in creep laboratory. Apart from creep laboratory Professor Banerjee visited various other divisions and sections. As a consequence he had a fairly good idea on the strength and weakness of this organization much before he got an offer to take over as its Director. He came with a clear vision & a broad outline of a plan to transform its work culture. This was also the time when it was extremely difficult to get enough plan grants to upgrade the basic infrastructure so crucial for the survival of aging laboratory. He was primarily responsible for major reorganization of the divisional structures, relocation of facility, introduction of documented procedures for project initiation, monitoring & closure. Some of the new concepts particularly those associated with project monitoring introduced in this laboratory are now being adopted at other places as well. Open door meeting involving all scientists, be it in-house committee or Research Council (RC) meeting originated from here.

During this restructuring I was inducted as one of the members in House Allotment Committee possibly because I was the only one who could use a computer. Dr Dhanjayan was the Chairman. One of the targets set by us was to display the eligibility list for allotment of quarters by the first week of January 1986. Preparation of this list was the main bottleneck for quick allotment of vacant quarters. The criteria of allotment were also very complex. There was no alternative but to take help of computer. Only facility available then was two Merlin computers procured in 1984 March / April for word processing. It had only two 8 inch 128KB disc drives. We started entering relevant data for all the employees in floppy drive in a tabular format using word processor. Most of these were done on weekends. The number of records and fields necessary to prepare the list were too large to be accommodated in one floppy. It had to be saved under different file names in several floppies. The final eligibility list was prepared by merging records from several files and running the sorting program. In spite of this it was possible to display the eligibility list for the allotment of quarters as per our target. The database was also used for the allotment of individual identity number for all employees. This was done by sorting the data in an ascending order of the date of joining NML. This helped us in demonstrating how use of computer could help in administrative work as well and make it more fair and transparent.

Here after there was no resistance in setting up computational facility in the laboratory. I was given the responsibility to set up new computational facility & to promote its use in scientific as well as administrative work. We got generous help from several institutes & organizations having prior experience. The support we got from Professor D B Phatak of CSE Department IIT Bombay is worth mentioning. He helped us prepare appropriate specs of a distributed computer net work with several terminals & accessories. We got overwhelming response from several suppliers of computers as soon as the query was floated. Professor Phatak was also involved in the selection of the final configuration and the vendors. A site (the present location of servers) was identified for setting up a new computer application division. It had to be thoroughly renovated to accommodate the proposed system. None of us had any formal training on running a computer network. We got co-operation from all. It took us nearly a year to refurbish the location & install the computer. I was fortunate to have a few dedicated colleagues (Dr K M Godiwalla & Dr Subroto Chattopadhyay) whose untiring efforts lead to the establishment of a new division under my leadership. This was formally inaugurated in the month of November 1987 by Dr V S Arunachalam the then chairman of Research Council of NML. Soon we realized how difficult it was to generate enough work to keep the system busy & in running order. We

were always on the lookout for a properly trained system administrator. It was extremely difficult to find one. Most of our time was spent in providing training & maintenance support. There were several eager learners from other divisions as well. Some of them helped us develop software for payroll preparation. This was being used by the bill section of NML until the new accounting package from CSIR was installed. Some used the drawing packages to prepare layout drawings of the entire laboratory. This proved useful for planning relocation of divisions and infrastructural facility. Soon after we realized that we have stepped into an area which has a very high rate of obsolescence. We were badly in need of additional funds to upgrade and also persons for technical support. Around 1990/91 it was possible to recruit a person having zeal & dedication to pick up operation & maintenance of computer system. With his untiring efforts and the generous support from major projects like Component Integrity Evaluation Program (CIEP), Steel Development Funded project on Blast Furnace & planned grants for modernization it was possible to upgrade the facility periodically with more modern & rugged system. It was possible to keep pace with the unprecedented growth in ICT during the subsequent decades. NML was amongst the first few laboratories under CSIR to provide access to internet & email through WAN with terminals located at every desk of scientists and administrative staff. The introduction of computers in 1987 was a major turning point in changing the face of NML.

Another major turning point was launching of Component Integrity Evaluation Program (CIEP) at NML, in August 1991. Initial plan started sometime around 1986/87. It was visualized as a multi sponsored project. In view of our interactions with thermal power plants and activities connected with Indian Creep Panel, it was identified as one of the promising areas where concerted efforts could be initiated to bring a large externally funded project.The initial proposal was prepared by Dr O N Mohanty around 1985/86. It was also the time when a few initiatives were taken to involve Petroleum Industries. This included investigations on the health of Haldia - Mourigram product pipeline segments having type III defects and cracking of Horton sphere of Gujrat Refinery of Indian Oil. Our proposal was sent to various funding agencies & potential customers like power plants & petrochemical industries. This was also the time when World Bank showed interest to support R&D activities by providing low interest loans. Our proposal was short listed by CSIR. We were invited by the WB team to present our case. It was possibly around June/July 1987.

Professor S Banerjee gave the responsibility to me to present our case. The meeting was arranged by Dr H R Bhojwani at CSIR head quarters. Our linkage with petroleum & power sector proved helpful. It was incidentally amongst the first few proposals accepted by World Bank for funding. It was going to be in the form of a long term interest free loan. The total project cost was worked out to be 6 crore. Detailed proposal in the format received from WB was subsequently prepared by Dr Amitav Roy who joined NML around May/June 1987. The idea of getting 50% of the total cost from the potential beneficiary was floated by us although WB could have given the full funding. The final proposal was presented before RC during 1988/89. Dr J J Irani was present as RC member. There were several important dignitaries of Tata Steel were also present as invitees. In fact the first encouraging response came from Shri P N Roy, General Manager Tata Steel. He said this could of considerable importance to steel plants. He cited as an example the importance of integrity assessment of critical components like crane hooks used to carry molten steel ladle. As far as I recollect they were the first sponsor of this program. The first installment of payment (25lakh 50% of the total commitment) was released soon after. With this initial encouragement it was possible to get 4 more sponsors namely Atomic Energy (AEC), Bharat Petroleum (BPCL), Indian Oil Corporation (IOCL) and Steel Authority of India (SAIL).

The project was unique in several respects. It not only focused on detailed plan of activities but also suggested a unique monitoring system. Program Management Board (PMB) was the apex body with members from each of the sponsor, WB representative and Director NML. Group leader of the project

was the convener. The next level was Project Technical Committee (PTC) with GL as the Chairman & representatives from sponsors as members. The overall technical activities were divided into 5 broad areas: High temperature creep, Fatigue & Fracture, Corrosion Base assessment, Non-destructive evaluation and Modeling & Simulation. The broad R&D activities were decided based on the feedback & needs of the sponsor. Apart from this there was provision to take up one sponsor specific work from every sponsor. The first meeting was held on 18 August 1991. Dr O N Mohanty, the first Group Leader of the project & convener of the PMB ably conducted the meeting as scheduled even though the same morning his father passed away in USA. Many of us came to know about it after the meeting. This was also the time when we were able to recruit some of the best young scientists to take up the challenging problems identified for this activity. Two of them now happen to be the key persons who could take the laboratory to greater heights. In fact some of them preferred to join NML even though they had offers from Tata Steel & other well known R&D establishment of the country. The PMB used to meet once a year & PTC twice a year.

The program was so well planned & structured that when Professor P Ramachandra Rao took over as the Director of NML in September 1992 it continued as per schedule. When Professor ON Mohanty left NML to join Tata Steel I became the group leader. However by then steps for procurement of new equipments were already initiated. A separate account was opened at Canara Bank, Bistupur at the instance of ICICI, Bank through which the World Bank fund was routed. The purchase procedure was also suggested by WB. A workshop was organized. This was attended by Dr Roy & me. It was indeed very helpful. We were able to insist staggered payment terms within 100% LC and extended warranty clause. We also had to insure all the equipment purchased through WB fund. All these proved extremely useful as we faced minimum problem in subsequent years in their upkeep and maintenance. Apart from fulfilling the commitments made to the sponsor, the facility was being increasing used for other organizations to generate funds to pay back the loan. During the course of the program a number of site work related to remaining life assessment of power plants were also taken up. In spite of the difficulties in reimbursing actual expenses one used to incur during site work we did get voluntary support from a few young colleagues. In one particular year total earning from such work did exceed 1crore. Although there were immense possibilities to increase ECF (external cash flow) through such effort, it could not be pursued because of the stringent TA/DA rules admissible for such work. Nevertheless laboratory based investigation that we were able to attract under this umbrella project, it was possible to refund the loan as scheduled from the external cash flow from this program. The last installment was paid in the year 2002.

A number of workshops were organized to disseminate the knowledge. Proceedings were also brought out. A few of these had excellent circulation. Professor P Ramachandra Rao also took a special initiative to bring out a special volume on Life & Integrity Assessment. This was brought out by Indian Academy of Science. This also had several articles from well known experts from abroad with whom we were able to establish close contacts during these years.

With better infrastructure & expertise it was subsequently possible to attract many challenging jobs. NML was also indentified as one of laboratories where failure & life assessment of aircraft components could be taken up. Innumerable failure investigations thereafter have been carried out at NML. Many of these have been highly appreciated particularly by IAF. The concept of Network Projects involving several laboratories under CSIR started during the 10^{th} five year plan. This is when Professor SP Mehrotra joined our Director. NML was identified as the nodal laboratory for a project involving life and integrity assessment of critical engineering components. New state of the art testing & characterizing facility needed for such activities were established. On the whole CIEP was indeed a land mark. This did

help us build close linkages with industries and focus our attention towards the development of tools and techniques needed for the life extension of ageing infrastructure.

Although I had to leave Creep Testing group after the establishment of Computer Application Division I did have close association with activities associated with life and integrity assessment of engineering components. This was possible because of my involvement in several projects apart from CIEP. In 2003 nearly a year after Prof Mehrotra took over as the Director of NML there was a major reorganization of the divisional structure of the laboratory. I became the Head of the Material Science & Technology Division (MST) having around 50 scientists. The division had four major groups: Material Evaluation where the focus on characterization of mechanical properties, Micro-structural characterization, Non-Destructive Testing and Advanced Materials where the focus was on synthesis, processing & characterization using non-conventional routes. I was fortunate to have active co-operation from every members of MST Division. During this period we got liberal funding from several sources. Bulk of it came from Planning Commission Grants for Network Projects and Department of Science & Technology (DST). The fund from DST was primarily for the establishment of Non-Destructive Testing (NDT) Facility. This was initiated at the behest of Professor P Ramachandra Rao. Most of the ground work was done by Dr DK Bhattacharya. Unfortunately he decided to leave NML to join CGCRI, Calcutta soon after the formal approval was obtained. The responsibility to fulfill the commitments fell on me. I got whole hearted support from Dr Amitav Mitra, Dr Narayan Parida, Dr Sarmistha Sagar, Dr Gautam Das and their colleagues. Today it happens to be one of the most active groups on NDT in India. The group has helped several industries all over the country in the evaluation of service induced damage assessment of critical components. A number of portable instruments have been developed for the integrity assessment of service exposed high temperature components like steam pipes in Power Plants or heater tubes in Petro-Chemical units. These are currently being used in several such units all over the country.

Professor Mehrotra nominated me to be a member of a multi-disciplinary task force set up by Ministry of Power; Government of India to look into the problem faced by the sudden shutdown of all the six units of Nathpa Jhakri Hydel Power Plant in Himachal Pradesh within a few months of its inauguration and suggest remedial measures. This is when I got an opportunity to visit several hydro-electric plants located in the Himalayan region. Severe erosion of several underwater parts of turbines was the major problem. This was primarily due to the presence of high amount of silt in the water. Parts made of hardened and tempered 13Cr4Ni or 16Cr5Ni steel was getting eroded within a few months. Therefore the plant had to be shut down as and when the silt content in the water goes beyond a threshold. The amount of silt in water found to be much higher than the permissible limit during April to September, when the potential for power generation is the highest. One of the suggestions of the committee was to develop silt erosion resistant steel for such parts. The responsibility fell on NML. The project started under my supervision in 2007. It involved several members from different groups at NML. Examination of damaged components suggested that there are specific locations that are more prone to erosion. We thought of developing steel whose ability to resist erosion would increase while it is in use. Initial trial looked encouraging. However I had to leave in February 2009 NML to join IIT Kharagpur; but my colleagues under the supervision of Dr S R Singh and Dr Sandip Ghosh Chowdhury did a commendable job. I am told that a component made of the new steel made at NML has given at least two and half times longer life than that of the conventional grade. If this could be up-scaled to produce Francis turbine blades and guide vanes it would indeed be a major milestone in combating the erosion problem being faced by the hydel-power plants in the Himalayan region of our country.

During eighties at NML,opportunity to interact with a foreign university or laboratorywas limited. Professor Banerjee asked me to explore the possibility of interacting with Professor Mike Ashby of

University of Cambridge. Since my interest was in the area of modeling of high temperature creep behavior of engineering materials he advised me to approach National Physical Laboratory (NPL), Teddington, UK. This is also the place where my PhD supervisor Dr Mitra spent a useful part of his career. In October 1988 I got an opportunity to visit NPL under TCTP program of British Council. Dr Malcolm McLean was my supervisor. I got associated with CRISPEN program developed by NPL and University of Cambridge. This was a menu driven software for **CR**reep **S**train **P**rediction of **En**gineering Materials. It was based on continuum damage mechanics describing the evolution of creep strain at a given stress and temperature by a set of state variables representing different forms of structural changes that occur in engineering materials during service. The exact forms of the coupled differential equations were derived on the basis of the dominant mechanisms of damage accumulation. Experimental studies had shown that apart from nucleation of creep cavities the creep of super-alloy was determined by dislocation (strain) softening whereas that in steel was due to coarsening of precipitates (time softening). The solver was developed using Turbo Pascal so that it could run on a desk top computer running on MSDOS. My initial task was to incorporate a solver that could estimate the material parameters in situations where both time and strain softening were important. My experience in setting up computer facility at NML proved handy. Within a short time I could pick up PASCAL language and incorporate the additional module that was assigned to me. Malcolm was extremely happy and I was asked to demonstrate the program to Professor Mike Ashby during one of his visits to NPL. Soon after this Malcolm asked if I couldhelp them develop a model that could predict the effect of crystal orientation on the creep behavior of single crystal super-alloy SSR99. This was developed by Rolls Royce and it was being used as blades in their aero-gas turbines. The cube <100>orientation was found to have the best creep resistance. The bulk of the creep strain time data that were available for this direction only. Could these be used to estimate the material parameters that could simulate the creep behavior of an arbitrary orientation? Luckily a few data set were provided to us by erstwhile Royal Aerospace Establishment (RAE) for <111> and creep data on a couple of complex orientations were also available for the validation of the predictive model.

This is where my experience in teaching a course on Dislocation Theory at IIT Kharagpur proved useful. There was a part that dealt with plastic deformation of single crystal. I used to explain the method of converting shear strain on specific slip systems into tensile strain using tensor notations. Creep too occurs due to dislocation glide on a set of specific slip system.Therefore the model used in CRISPEN had to be reformulated in the form of shear stress and shear strain. The accumulated strain in each of these had to be compiled and transformed into tensile creep strain. The number of operating slip system was at least 12. There were doubts if this could be implemented in a desktop computer. Nevertheless very soon I was able to develop a solver that could predict orientation dependence of creep behavior of single crystal using a desk top computer. The stay was so productive that the interaction with Malcolm McLean continued for over 15 fifteen years even though he moved to Imperial College in 1990. He as well as some of his colleagues (Brian Dyson) did visit NML on several occasions. We were also successful in getting EPSRC UK supported project on modeling & simulation of creep of super-alloy. One of our colleagues got an opportunity to work at Imperial College for a couple of years. The collaboration culminated in organizing 2day workshop on Physically Base Constitutive Models for High Temperature Materials at National Aerospace Laboratory, Bangalore in January 2004. Apart from Dr Sanjay Sondhi & me there were lectures by Prof McLean, Prof Brian Dyson, Dr Hector Basoalto & Professor David Hayhurst of UMIST, UK. It was attended by over 30 participants from various industries & academic institutions.Unfortunately the following year Professor McLean passed away. My association with him was indeed a turning point of my career.

In 2009 I came back to teaching after a gap of 26 years. I joined the Department of Metallurgical and Materials Engineering at IIT Kharagpur as a Chair Professor. I am currently offering two courses one on Design & Selection of Materials and the other on Metallurgical Failure Analysis to under graduate students. This gives me a chance to share my long experience in helping several industries solve their problems related to processing and performance of a wide range of materials. When we were student in late sixties, the choice of materials for design and fabrication of engineering components was limited. Today the options are too many. Even in the case of steel the most common material of construction the number of new grades introduced after 1980 far exceeds the total number of grades that were available till then. While I was in UK, I got chance to spend a week at the University of Cambridge to interact with Professor Ashby. This was the time he was involved in the compilation of material database in an organized fashion. This was being used to generate material selection charts for various applications. He had given me several of these which I shared with my colleagues at NML. This is when I realized that the way we introduce the wide range of materials of construction to engineering students is far removed from real life application. The approach is likely to change soon. Today it happens to be one of the main objectives of granta.com an organization established by Professor Ashby. I do often visit their website and ask my students to do so while offering these courses. With the growing availability of wide range of information on the net and the ease with which these can be accessed the way these courses are being taught in the class is going to change. I got an opportunity to offer a course on Principles of Physical Metallurgy under the NPTEL program of the Ministry of Human Resources of our country. The video version is available on the net and the web version is likely to be uploaded soon. It may be too early to judge if it is useful to students interested to learn about structure and properties of metals and alloys. However students occasionally raise interesting questions. I enjoy answering these. All this has been possible because of my long association with IIT Kharagpur and NML Jamshedpur; establishments that recently celebrated their Diamond Jubilee.

I shall fail in my duty if I do not acknowledge the support that I have received from my family particularly my wife Jayasree. We were married in 1976. She was brought up in Pune where her father worked initially as a scientist in Explosive Research & Development Laboratory and later as its Director until 1979. In spite of her good educational background she preferred to be a home maker and managed it efficiently. We have a son and a daughter. Both are married and settled. We have a grandson too. He has just started going to nursery school. This makes me think what kind of future lies ahead of the present school going children in the face of stiff competition and growing peer pressure. We were possibly lucky to have gone through this stage when there was little peer pressure and relatively relaxed curriculum. It is true that knowledge is going to expand exponentially. However human capacity to assimilate and use itis limited. We have to depend on new tools and techniques that help us exploit it fully. The problem can never be solved by expanding the syllabus and increasing the work load in schools and colleges. Learning does not end with graduation. One has to keep learning all through his career. Therefore one of the main objectives of every academic institute should be to promote self learning and provide an environment that promotes it. Physical insight and experimental skill are often not enough to solve a challenging problem in any discipline of engineering you must have the ability to combine these with mathematical rigor. A flexible curriculum that suits the aspiration of students and the social needs may help this happen.