Physicist or Metallurgist

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I was born in 1935, and obtained my BSc (Honours) and MSc in physics from the Madras University and subsequently doctorate from the Bombay University. I am happy that I am a part of the development of Indian metallurgical profession.

Are you a physicist or a metallurgist was a question that was posed to me during my early career. In fact, after working at the Metallurgy Division of the Atomic Energy Establishment Trombay for about 5/6 years, and having presented a few papers in the Annual Technical Meetings of the Indian Institute of Metals and publishing papers in its journal, the 'Transactions of the IIM', I applied for a membership of the IIM, which was promptly turned down because I did not have a basic metallurgy degree. Those were the days when 'Materials Science' was not yet prominent as a discipline. I knew that if the IIM were to recognize me as a metallurgist by profession, then I should get an overseas recognition first. Based on my PhD on 'X-ray line broadening studies on cold worked metals and alloys', and my publications, the Institution of Metallurgists, UK elected me a Fellow, considered equivalent to a PhD in metallurgy in UK and elsewhere. After this, IIM did not have any hesitation in accepting me as a member. Later on, I was even elected as the President of IIM in 1993. I was elected as a Fellow of the Indian Academy of Science (FASc) in 1982, Fellow of the Indian National Science Academy (FNA) in 1986, Fellow of the Indian National Academy of Engineering (FNAE) in 1988, Fellow of the National Science Academy of India (FNASc) in 1992, Fellow of the Aeronautical Society of India (FAeSI), and Fellow of the Astronautical Society of India (FASI). All of them are based on my research outputs in metallurgy.

The Transition

How did I transit form a physicist to a metallurgist? After my MSc in X-rays and crystallography, Prof. GN Ramachandran who was the Head of the Department of Physics at the University of Madras wanted me to continue there for my PhD and I had started my work. But then he had had a nervous breakdown and did not show up in the laboratory for a few months. At that time (1957), Atomic Energy Establishment Trombay started a training programme and was looking for graduates and undergraduates in different disciplines for working in the nuclear energy programme of the country. Because I had the privilege of travelling free in Indian Railways, thanks to my father being in the Railway service, I attended the interview at Bombay. I was selected and when I reported for joining the Training School, I was asked to undergo chemistry training as X-ray crystallography work was being carried out in the Chemistry Division. I met Dr. Raja Ramanna who was in charge of the Training School and explained my predicament; he changed me to the physics stream. On completion of this one year orientation course, I was posted to work with Dr. PK Iyengar in neutron diffraction, in the Nuclear Physics Division.

Just 4/5 days before my joining the Nuclear Physics Division, Ramanna told me to meet Dr. Brahm Prakash, Head of the Metallurgy Division. BP told me about the CIRUS reactor programme and that Dr. Bhabha wanted AEET to fabricate half the requisite quantity of metallic uranium fuel elements required for the reactor. One of the critical factors to be assessed in metallic uranium fuel is the texture or the crystallographic orientation. Dr. K Tangri, who had done his doctoral work on texture studies in the USA, was there. As I was the only person from the training school who had

the requisite background, BP asked me to join his division. With continuous smoke emanating from BP's cigarette and puffs from Tangri's pipe, I was a little dazed and I told them that I would think it over and meet them the next day. I met BP the next day and told him that I would join the Metallurgy Division. He said he would keep me happy and he did. This was the starting point for my conversion from a physicist to a metallurgist.

My BARC Days

I started my work right earnestly and used to collect samples of fuel rods from the Fuel Fabrication Facility, (code named 'Fagots') to determine the texture and to confirm that quenching from the high temperature beta phase has led to a random texture. The samples have to be metallographically polished and MK Asundi helped me a lot in this regard. I also learnt my basic metallurgy from him. As the work load was increasing, BP told me that if I required, he would post a physicist from the 2nd batch of Training School to work with me and thus VS Arunachalam joined me. I should mention here that the life of the metallic uranium fuel rods made by us in Trombay was twice that of a Canadian fuel element in the same reactor.

I should also mention an interesting anecdote in this connection. Bhabha used to review the progress of uranium fuel fabrication, to which I was always invited. In one of the meetings, when some wrong interpretation was presented, I got up and started talking. Bhabha stopped me and asked BP who was sitting next to him: "I say, did we ask him to say anything?" BP told him that I am working on textures in uranium and that I should be heard. Later on, when the source of natural uranium for fuel making was changed, the fuel rods started shrinking, instead of the anticipated marginal growth. I examined the texture of the fuel rods again and suggested a small cold-drawing operation after beta quenching. Rods that underwent such a treatment behaved better with no shrinkage/growth. This work earned me a promotion almost without an interview.

I was sent to CEN de Saclay in France for training for a year. I did not find the training at Saclay of any use to me and as I was left alone, I started working on stacking faults in uranium and predicted how faults can occur in alpha uranium, which was confirmed experimentally later on. After a 6 months at Saclay, I switched to Laboratoire de Physique de Solid at Orsay to work with Prof. Andre Guinier, on X-ray small angle scattering of irradiated quartz. I found that under neutron irradiation amorphous regions started forming in small pockets, while the crystalline structure was retained. This surprised Prof. Guinier. This stay at Orsay enabled me to have a few fruitful discussions with Prof. Friedel and Prof. Castaing.

On my return to Trombay, I found that Dr. NM Parikh had joined the Ceramics Section after his doctorate from MIT, USA. He told me that I should look up Warren and Averbach's papers on X-ray line broadening and that may be a good topic for my doctoral work. I should thank him for this as I did take his suggestion seriously and registered for my PhD in physics with the Bombay University with Raja Ramanna as my guide. I submitted my thesis just after two years in 1966, but had to wait for a year for my thesis defence. Prof. S Ramaseshan was my thesis examiner. The main finding in my thesis was that when you cold-work an alloy whose composition is very near the FCC/HCP phase boundary, the alloy easily transforms from one structure to the other. But, the major satisfaction from X-ray line broadening studies was that our work on cold-worked uranium was accepted for publication in Acta Metallurgica. This is the first paper to be published in Acta from an Indian research group.

At that time, Dr. VK Moorthy was working on sintering studies on UO_2, used as a fuel in nuclear power reactors. He found that UO_2 powders derived from different routes showed differing sintering behaviour. I told him that we need to characterize the powders better and suggested looking at the crystalline structure of these powders. I did a lot of line broadening studies and estimated the particle size and the degree of crystallinity in the powders and related them to their

sintering behaviour. Powders which were fine in the range of 20 to 40 nm sintered to a higher density at lower temperatures. I wish I had used the term, 'nano particles' then.

Subsequently, I was asked to look after the electron microscopy work. We started from scratch and learned preparation of thin films of metals and alloys to get familiarity with the techniques of microscopy and electron diffraction. The group got strengthened when P. Mukhopadhyaya and Srikumar Banerjee joined the team. We studied phase transformations and structure property correlations on a wide variety of alloys based on zirconium, titanium and some steels. We published several articles in Acta Metallurgica and Metallurgical Transactions. The basic research carried out enabled us to solve the production problems faced by the Nuclear Fuel Complex when they did not obtain the strengths expected of zircaloy tubes. Subsequent to my departure from BARC, I was happy to learn that my former colleagues had a major role in establishing the flow sheet for the production of Zr-Nb tubes. I should also mention here that Banerjee once questioned me about the usefulness of doing basic research and how does it help the country and the public. I told him how things get connected and he realized later that it was essential to do basic research to understand the behaviour of materials so that when problems are faced in operation or by the production agencies, they could be solved by the researchers. I am happy that subsequently he became the Chairman of the Atomic Energy Commission and Secretary, Department of Atomic Energy. He was my second colleague in reaching the top position in the Government, the first one being VS Arunachalam, who became the Scientific Advisor to Raksha Mantri and Secretary, Department of Defence Research & Development.

BARC was the first to acquire a scanning electron microscope in the country in 1974 and I was asked to look after that. I had initially trained GE Prasad, who became an expert in using this instrument and in interpreting the micrographs. He had carried out a lot of studies of different nature, including failure analysis investigations with Asundi. ESCA and Auger spectrometer was the next big instrument that I handled at BARC. We were planning to carry out a few surface analytical studies of nuclear materials with this. I was particularly interested in evaluating the additions made to Zircaloy 2, to understand its surface behaviour.
It was March 1982, when Ramanna as Director, BARC asked me to take over as Head Metallurgy Division. However, Physical Metallurgy was separated out and Asundi was asked to head that Division. While I was a little unhappy in having to leave the excellent structural metallurgy group that I had built up over the years, I was happy to learn about the confidence Ramanna had in my ability to handle the Metallurgy Division.

My Transition to DRDO

Arunachalam was looking for a Director for the Naval Chemical and Metallurgical Laboratory located at the Naval Dockyard of Bombay. He first convinced me to join NCML and later talked to Ramanna to release me on deputation to DRDO. After taking his concurrence, he had to seek approval from Shri. PV Narasimha Rao, who was then the Defence Minister. The minister was away in Russia in the last week of February 1985 and on his return on 27th February, Arunachalam got my appointment as Director of NCML approved and flew into Bombay on 28th February morning, got Ramanna's approval and took me to NCML and introduced me to the staff there. I mention this in detail because only Arunachalam could have done it in such a short time; no one else!
NCML was a relatively small laboratory in DRDO with staff strength of about 300. While there were excellent facilities available in the laboratory, not much of basic research was being carried out, except in one or two groups. I found out later that research was not a priority in many DRDO laboratories. I introduced a research culture by asking two of my senior colleagues to register for their PhD with IIT Bombay and IIT Kharagpur in metallurgy. Both of them got their degrees within three years. Another scientist obtained his PhD from IIT Bombay for his work on PZT transducers and he was able to get some good publications in international journals. For the first time, I made the paints group publish their work in an international journal. I initiated some new programmes on

naval bronzes, brasses and molybdenum bearing steel. I was happy that in a short period of 3 years, I had changed the complexion of the laboratory.

I was the chairman of the Materials Advisory Committee for the 'Advanced Technology Vessels' programme. I was responsible for the Indian Navy rejecting the age old AK 25 steel as the hull material which the Russians were recommending for our nuclear submarine; they then came out with a much better material called AB grade steels with very good mechanical properties, weldability and corrosion resistance. The Defence Metallurgical Research Laboratory later on indigenized these grades of steels. I consider the induction of AB steels as my major contribution to the nuclear submarine programme.

One day in March 1988, Arunachalam told me that I should come to DRDO Head Quarters to take up the position of Chief Controller R&D. I resisted initially as this was a pure desk job, but I yielded. At one stage, I was assisting more than half of the technical laboratories. I was also in charge of the human resources development. But, I got bored doing this desk job as CCR&D and requested Arunachalam to send me back to a laboratory. He gave me a couple of options and I chose to be posted as Director of the Gas Turbine Research Establishment at Bangalore with effect from 1st January 1990. I was not a gas turbine specialist, but materials problems of the engine contributed to more than 50% in the engine development. Kaveri design incorporated the use of a variety of nickel base superalloys and titanium alloys. Thus, I was sure of making my contributions in the development of the engine.

Unlike NCML, GTRE, a major systems laboratory had more than 1500 employees and a strong employees union. It had built the after burner for the Orpheus 703 engine, but that was not accepted because it was over-weight. It had built two technology demonstrator engines designated GTX 37-14U and GTX 37-14UB, the former being a straight jet, while the later a bypass version. This had given confidence to GTRE to bid for building the flat rated gas turbine engine (Kaveri) for the Light Combat Aircraft. The design of the Kaveri engine was based on a mixture of eastern and western philosophies. Obviously, several problems did surface. Prior to my joining GTRE, reputed jet engine manufacturers like Rolls Royce, Snecma and General Electric had shown interest in participating in our engine development programme, but that was turned down due to some reason or other. After my joining GTRE, Mr. Peter Chipporus, a retired chief designer from GE came for discussions and based on his suggestion, the number of stages in the high pressure compressor was increased from 5 to 6. Also, it was brought out that the engine design dimensions specified correspond to the operating conditions and one needs to take into account thermal as well as centrifugal expansion to arrive at the dimensions for manufacturing. Another problem pertained to dimensional distortion due to residual stresses arising out of welding/machining. I assisted in developing a step wise annealing schedule to reduce the distortion to the minimum.

Most of the superalloys required for the manufacture of various discs and blades were initially imported, but later MIDHANI developed all the alloys which were certified by CEMILAC, the agency for certification of materials for air-worthiness. From the designers' point of view, it was necessary to generate adequate data of the materials in use and hence a separate facility, Aeronautical Materials Testing Laboratory, was established near Midhani.

While most of the engine testing facilities was available, we had to go overseas to get some specialized testing done. Russia offered these tests at a lower cost, but procedural delays were considerable. GTRE had 5 engine test beds and it used to test the prototype only once a day. I suggested that it has to be done more number of times a day, as otherwise we may not be able to meet the project schedule. And it was done. My moment of happiness was when the first prototype of Kaveri was test run in 1994.

I should also mention here that even though we had turned down the offer of collaboration from other engine manufacturers earlier on, in one of my visits to Moscow in 1994, our ambassador in Moscow Mr. Ronen Sen, told me that after Glasnost, Russian experts are available at a paltry honorarium of US $ 1000 per month. He said that if I need a couple of them, he would arrange to send them to GTRE. I did not have the authority for this and the ambassador's suggestion did not fructify. Had that happened, may be Kaveri would have been flying in LCA now.

I had just 6 years in GTRE and personally felt that part of the problem that GTRE was facing in the project work was due to lack of adequate research experience on the subsystems of the engine. Having worked in BARC, which has a high level of research culture, I initiated a few basic research programs. The DG, DRDO wanted me to continue beyond my retirement date (December 1995), but I had told him a year earlier that I would quit on reaching my superannuation date which I did.

Post Retirement

Post retirement, I assisted a NRI in setting up a laboratory named 'Shiva Analyticals' for chemical and metallurgical analysis at Hoskote, near Bangalore. I was the CEO, drew up the plans, got the building built, procured the necessary equipment and recruited scientists to run the lab. As there was a cash flow problem, the metallurgical analysis part was getting delayed, and hence I quit the organization (1998), because Chemistry was not my forte.

I then assisted Agastya International Foundation (www.agastya.org), an NGO created to inspire a scientific temper in disadvantaged rural school children. My part was more in training the rural teachers. I still continue to be associated with Agastya but to a lesser extent.

In the meanwhile VS Arunachalam who founded a not-for-profit NGO called 'Centre for Science, Technology and Policy' (www.cstep.in) asked me to join them as an advisor. I worked there for a couple of years during 2011-2013 and assisted them in writing one report on 'Rare Earths and Energy Critical Elements' for the Ministry of Mines, Government of India and another report on 'Concentrated Solar Power' for the Ministry of New & Renewable Energy.

I should also mention my association with KK Sinha and V Ramaswamy in bringing out a document titled 'Successes and failures of metallurgical R&D in India' for the Indian National Academy of Engineering. I enjoyed writing this very much.

Concluding Remarks

I would like to mention that for a successful career, one needs to be lucky to have good bosses. I was lucky in having understanding bosses like MK Asundi, Brahm Prakash, CV Sundaram, PK Iyengar and K Balaramamoorthy in BARC and VS Arunachalam in DRDO. It does not mean that I was always lucky but I survived. I would like to mention here what Dr HN Sethna, Chairman AEC, said at his retirement farewell function; "I have learnt to suffer fools during my service in DAE". May be I did not learn that.