Srikumar Banerjee (1946–2021)

Dr Srikumar Banerjee passed away in the early hours of 23 May 2021 in Navi Mumbai. In his passing away, India has lost a leading metallurgist, a friendly human being, an excellent mentor, and a probing mind. He was born on 25 April 1946. He completed Bachelor of Technology in Metallurgical Engineering with First Class Honours from the Indian Institute of Technology, Kharagpur in 1967 and joined the Training School in Bhabha Atomic Research Centre (BARC). He completed the orientation course in nuclear science and engineering in 1968 and started working as a Scientific Officer in the Metallurgy Division, BARC. During very early years, Banerjee showed the first glimpse of his technical and scientific brilliance when he displayed his mastery over the martensitic phase transformation in lesser-known zirconium-based alloys. By predicting the habit-planes of different variants of martensites using phenomenological theory of martensite and experimentally confirming these using transmission electron microscopy, he examined the internal structure and crystallography of martensitic transformation in zirconium alloys. This work was published in *Acta Metallurgica*, the most coveted journal in metallurgy. He also did extensive work on the tempering of martensites in zirconium alloys. Based on his research in BARC on martensitic transformation in zirconium alloys, he obtained a Ph.D. in 1973 from the Indian Institute of Technology, Kharagpur. He was also awarded the INSA young scientist medal for the aforementioned work.

He visited the School of Engineering and Applied Sciences, the University of Sussex, Brighton, England as a post-doctoral fellow during 1978–79. There he explained the structure of the ordered omega phase in a totally new way and laid the foundation of a new class of hybrid transformation which later became one of his life time pursuits in research. He also did work on zirconium-based metallic glasses. Seeing his scientific acumen, R. W. Cahn and B. Cantor became his admirers and life-time friends. From UK he went to Germany as a Humboldt Fellow and worked at the Max-Planck Institut fuer Metalforschung–Institut fuer Physik, Stuttgart, Germany and at KFA Forschcungszcentrum, Juelich, Germany. Here he studied phase transformation in Ni–Mo based alloys. His study of *in-situ* ordering in Ni–Mo alloys under high voltage electron microscope brought a paradigm shift in the understanding in the field of order–disorder phase transformation. This work by him was one of the first experimental verification of the concept that irradiation-induced transformations can be reversible and was published in *Acta Metallurgica*. The excellence of this scientific contribution was much appreciated by scientific community and on its publication, he was given one of the most prestigious 'Acta Metallurgica outstanding paper' award. His proposition of combining two mutually exclusive

processes, viz. ordering and clustering lead to the concept of spinodal ordering. He along with his colleagues, showed that if these two opposing tendencies are expressed in the form of concentration waves, both the tendencies can be combined and the wavelength will decide which of the tendencies will eventually prevail. He made a comprehensive study on both displacive (martensitic and omega) and diffusional (chemical ordering, precipitation, spinodal decomposition and eutectoid decomposition) transformations encountered in these alloy systems.

He studied all the possible phase transformations in zirconium-based alloys, their structure–property correlation and texture development making him unique in terms of zirconium metallurgy. This knowledge bank helped in zirconium-based alloy processing in Nuclear Fuel Complex (NFC) and made the country fully self-reliant in zirconium alloy development and manufacturing. This knowledge bank lead to the publication of the book, *Phase Transformations: Examples from Titanium and Zirconium Alloys* by S. Banerjee and P. Mukhopadhyay, Elsevier, London, 2007.

He explored various means of inducing phase transformations under conditions far from equilibrium. These include rapid solidification from the liquid phase, exposing materials under high shock pressure and radiation. These studies yielded several original findings in the areas of amorphous and quasi-crystalline structures, order–disorder transitions in alloys experiencing the competition between multiple super-lattice structures, displacive beta (bcc) to omega (hexagonal) transformation and mixed mode transformations.

One of the phenomena he had been passionately working on is Portevin le Chatelier effect in metals and alloys. His work on plastic flow behaviour of a β-titanium alloy (Ti–15% Mo) brought out the interplay between dislocation motion and dynamic precipitation resulting in deformation band formation leading to serrated flow behaviour. He pursued his interest in nano-indentation instabilities, indentation size effect (ISE), deformation of irradiated samples and formulation of mathematical framework for acoustic emission during plastic deformation.

Besides his contribution to flow sheet development for manufacturing Zr–2.5 Nb pressure tubes in NFC, he ensured that the scientific work done in BARC also translated to technology in other areas. Studies in his group on martensitic transformations and shape memory effects have resulted in the development of shape memory couplings which are extensively deployed in Indian Light Combat Aircrafts (TEJAS). A plant for the production of shape memory alloy components has been set up by Aeronautical Development Agency in Bengaluru with the technology provided by BARC.

He believed that the academic research creates the knowledge bank which ultimately helps in the development of indigenous technology. He himself did high level of academic research in a variety of areas. Though he was an experimentalist, he had strong interaction with scientists involved in theoretical work. He wanted experiment and theory to go hand in hand. He wanted to ensure that science gets transformed to technology.

Many scientists go through the dilemma of rigour and relevance. In this regard,

one may recall words of Donald Schon, who was a designer and a philosopher and said, 'In the varied topography of professional practice, there is a high, hard ground overlooking a swamp. On the high ground, manageable problems lend themselves to solution through the use of research-based theory and technique. In the swampy lowlands, problems are messy and confusing and incapable of technical solution. … The practitioner is confronted with a choice. Shall he remain on the high ground where he can solve relatively unimportant problems according to his standards of rigour, or shall he descend to the swamp of important problems…' (Donald Schon, 'The new scholarship requires a new epistemology', *Change: The Magazine of Higher Learning*, 1995, **27**(6)). Banerjee worked in the field of phase transformations in metallic alloys. Based on the understanding of the basic phase transformation mechanisms, he developed the thermo-mechanical processing routes for zirconium alloy components, especially pressure tubes, used in Indian Pressurized Heavy Water Reactors. Here you see pursuit of both rigour and relevance together – a connect between the high hard ground and the low lying swamp. The same is true for his work on shape memory alloys.

Banerjee became Head, Metallurgy Division in 1990, Associate Director in 1996, Director, Metallurgy Group in 2001, and Director, BARC in 2004. As Director of BARC, he coordinated research and development activities in physical, chemical, materials and biological sciences, design and developments related to the next generation of nuclear reactors, and applications of radiation and isotope technologies in health-care, agriculture, food preservation and treatment of municipal waste. Strategic programmes such as isotope enrichment, spent fuel reprocessing, and immobilization of nuclear waste, were given the due emphasis. In spite of his busy schedule, he never left science or gaze of his eyes on the latest development in materials. He was instrumental in creating several research facilities like high end transmission electron microscopes including the country's first aberration corrected microscope, structure property correlation facilities at all length scales from nano to component level and micro-texture measurement. He promoted access of these instruments to a wide spectrum of users and believed in self-maintenance of the equipment. He brought all microscopy groups together and rejuvenated Electron Microscope Society of India. Today it is one of the most vibrant societies on electron microscopy in the world. He encouraged indigenous development of instruments. The hot hardness tester and the indigenous SEM developed by BARC bear testimony to this fact. He was the president of the Indian Institute of Metals (IIM) and showed his organizational skills by conducting one of the most successful Annual Meetings. He also contributed to the growth of IIM by encouraging different chapter level activities.

In November 2009, he was elevated to the position of Secretary to the Government of India and Chairman, Atomic Energy Commission and continued in this position up to April 2012. As the Chairman, Atomic Energy Commission, he worked for augmentation of the front-end and the back-end of the nuclear fuel cycle, interacted extensively with legislators, industry leaders, intelligentsia, journalists and inhabitants near nuclear installations to explain the safety issues and the benefits of nuclear power generation and allied activities. He continued to promote international scientific collaborations and academic activities of the Department. Coming soon after the relaxation of its guidelines by the Nuclear Suppliers Group to facilitate international cooperation with India, his tenure as Secretary saw surfeit of activity and he did whatever was necessary with enthusiasm.

Subsequently, he was Homi Bhabha Chair in BARC for five years and he intensified his research in the field of metallurgy of actinide systems and evolving nuclear fuel cycle. He was involved in the research councils and governing boards of several national institutes and research laboratories, supervision of Ph.D. students and extensively lectured on materials science and nuclear energy.

Post superannuation, Banerjee started interacting with several research groups in India and abroad and held visiting positions overseas as well as in India. Through these interactions, he started activities on laser processing of materials, high entropy alloys, phase transformation in uranium-based alloys which drew attention of international community towards these fields. Recently he proposed another class of transformations for which he coined the word 'lattice correspondence phase transformations'.

Banerjee was a recipient of many national and international awards and honours. National awards include Indian National Science Academy (INSA) Young Scientist Medal (1976), National Metallurgists' Day Award (1981), Shanti Swarup Bhatnagar Prize in Engineering Sciences (1989), Materials Research Society of India (MRSI) Medal (1990), G.D. Birla Gold Medal of The Indian Institute of Metals (1997), Indian National Science Academy (INSA) Prize for Materials Science (2001), MRSI-Superconductivity and Materials Science Prize (2003), Indian Nuclear Society Award (2003), MRSI Distinguished Materials Scientist of the Year Award (2008), Indian Science Congress Association's Excellence in Science and Technology Award (2010) and MRSI–CNR Rao Prize in Advanced Materials (2011). Notable among the international awards are Acta Metallurgica Outstanding Paper Award (1984) and Alexander von Humboldt Research Award (2004), William J. Kroll Award of ASTM (2012), R W Cahn Award of JNM, and the Presidential citation of American Nuclear Society (2012).

Banerjee was a fellow of all science and engineering academies of the country, and the World Academy of Sciences. He was bestowed with 12 honorary doctorates. The Government of India honoured him with a Padma Shri in 2005.

Banerjee will be remembered by all who had the privilege of working with him and knowing him. The first author remembers him as his doctoral supervisor, and the second author worked closely with him as the Principal Adviser, when he was the Chairman, Atomic Energy Commission and recalls his enthusiasm and capacity to work for long hours.

He is survived by his wife, and a son and his family.

GAUTAM KUMAR DEY[1]
R. B. GROVER[2,*]

[1]*Materials Group,*
Bhabha Atomic Research Centre,
Mumbai 400 085, India
[2]*Homi Bhabha National Institute,*
Mumbai 400 094, India
**e-mail: rbgrover@hbni.ac.in*