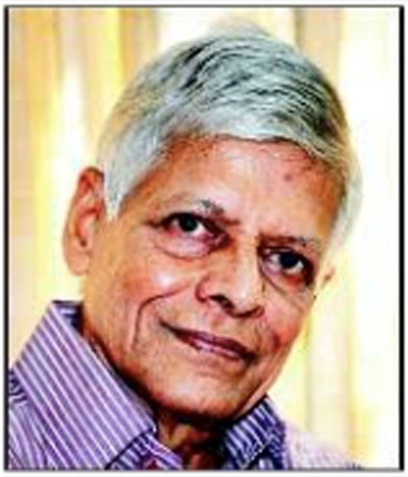
M. Srinivasan (1936–2020)

Dr M. Srinivasan, an outstanding nuclear physicist, was born in 1936. He was selected to join the first batch of the BARC Training School, though he had a BTech degree in Textile Physics preceded by an earlier BSc degree in Physics, both from Madras University. On completion of a year's training with good grades, he was assigned to the Neutron Physics Division in 1958, which was headed by Raja Ramanna and began work on experimental reactor physics at Apsara reactor that had been commissioned in 1956.

Around 1960, Srinivasan was sent to visit the Experimental Fast Breeder Reactor in USA, as part of a three-member team. After his return, he moved to ZERLINA, a zero energy reactor that had just been commissioned specially for study of criticality of different fuel lattices in heavy water reactors of the kind India had chosen to adopt. Srinivasan spent a year in Canada on sabbatical during 1969–70. Meanwhile, indigenous plutonium had become available and BARC considered building a Pulsed Fast Reactor as a source of neutrons for physics studies. As a prior step, construction of a zero power fast reactor PURNIMA (Plutonium Reactor for Neutronic Investigations in Multiplying Assemblies), with plutonium oxide fuel and beryllium reflector was planned under the keen supervision of P. K. Iyengar. The responsibility for design, safety analysis and safety clearances fell on Srinivasan. In defending the safety case for this reactor, he did his homework exceedingly well with convincing answers to the many valid searching questions the committee raised. PURNIMA reactor became operational in 1972. Srinivasan and his team undertook study of the multiplication behaviour of neutrons in the unmoderated core and arrived at some simple empirical relationship to predict the critical mass. Shortly thereafter, the reactor was dismantled and its plutonium content was used for the first underground nuclear test conducted by India in 1974. That provided a valuable opportunity for him to study approach to criticality in unmoderated plutonium metal assembly meant for the purpose.

When about 400 grams of Uranium-233, another isotope of uranium that can serve as fuel for a nuclear reactor, became available in BARC, Srinivasan was challenged to find a way of using it. He and his team undertook to build a critical facility with just that much material in the form of uranyl nitrate solution. This was possible because of the use of BeO as reflector unlike other earlier experiments with Uranium-233 elsewhere that chose paraffin reflector and performed only subcritical experiments. This facility, called PURNIMA2, became operational in 1984 and enabled the measurement of neutron multiplication in an extremely



sub-critical assembly by varying the level of the fissile solution. Based on a range of experiments with plutonium and uranium 233 with extension by calculations, he and his colleagues were able to arrive at a simple and general relation known as the Trombay Criticality Formula. This permitss prediction of effective neutron multiplication in small assemblies of fissile actinides for varying core size, shape, density, whether bare or surrounded by reflectors of different thickness. A useful application is estimation of criticality risk for a lump of the fissile material deformed in shape during an accident.

The criticality experiments with the uranyl nitrate solution were terminated in 1986 and Srinivasan was charged with the work of design and construction of the reactor KAMINI (Kalpakkam Mini) with fuel plates containing a metallic alloy of aluminium with 20% Uranium-233 recycled from the earlier solution reactor. This was first demonstrated at Trombay in 1992 and then set up at Kalpakkam in 1996. His colleague C. S. Pasupathy played a major role in this effort. The initially envisaged purpose of KAMINI was to enable neutron radiographic examination of nuclear fuel pins of FBTR reactor to assess possible impact during their use in the reactor. Since its operation, it has been highly useful for other vital applications like examination of pyro devices used in launch vehicles of ISRO and neutron activation analysis for forensic purposes. The study of additional neutrons produced in the beryllium reflector used in the Uranium-233 experiments led Srinivasan to examine the possibility of harvesting neutrons from the beryllium reflector proposed for fusion reactor systems to convert fertile thorium into fissile Uranium-233 in line with the concept of fusion–fission breeders.

Srinivasan was conferred the DSc degree by Bombay University in 1988. As Head of the Neutron Physics Division from 1991, he oversaw activities that included accelerating light and heavy ions to GeV levels using relativistic electron beams. With protons so accelerated, a source of spallation neutrons could be generated to convert fertile thorium into its fissile version without having to wait for fusion reactors. This was in continuation of an earlier study with plasma focus and deuterium gas to produce pulses of neutrons of useful strength for various investigations.

Immediately after the dramatic announcement of Fleischmann and Pons on 'cold fusion', in March 1989, instructed by Iyengar who was BARC Director at the time, Srinivasan coordinated cold fusion experiments by 12 teams with 50 scientists from various divisions in BARC. These showed generation of tritium in the electrochemical environment of palladium and heavy water and was confirmed by other groups elsewhere. The appearance of a nuclear product indicated a nuclear process. In December 1989, a US team visited BARC to learn about the work. Iyengar and Srinivasan visited Stanford Research Institute in USA in 1990 with results of dozens of BARC experiments which clearly indicated that something new and nuclear was occurring in the solid state in ways not well understood. At the First Annual Conference on Cold Fusion held in USA in 1990, an International Advisory

Committee was set up with Srinivasan as a Founding Member. In November 1993, Srinivasan took a six-month sabbatical from BARC and joined the Energy Research Center at SRI (formerly Stanford Research Institute) to plan and perform a series of experiments with palladium and ordinary water.

Both Srinivasan and Iyengar firmly believed that experimental observations are subject to rigorous tests for validation, but cannot be set aside on the basis of theory alone. The field of research known initially as 'cold fusion' is now more generally as Low Energy Nuclear Reactions (LENR) and even more generally as Condensed Matter Nuclear Science (CMNS).

Srinivasan retired in 1996, but his active interest in LENR lasted beyond his tenure in BARC. He was a regular attendee, at his own expenditure, at the International Conference on Cold Fusion held annually. His research contributions are seen by the LENR community as many, varied and exceedingly positive. He was specially interested in reports presented in these conferences of biological transmutation of radioactive caesium into a stable isotope faster than radioactive decay as it provided a path facilitating radioactive waste management. He became a keen follower of the experimental investigations in biological transmutations. Several attempts were made by him to get Indian scientists interested in studying LENR.

In 2008, he organized a one-day discussion meeting under the auspices of NIAS, Bengaluru on New Energy Concepts for LENR. In 2011, he organized the International Conference Cold Fusion in Chennai. Not being affiliated to any scientific institution in the country, he had to work by himself to get the various Ministerial clearances at the state and central level. The Indian Nuclear Society co-hosted the symposium. Spread over five days, the conference had 67 presentations by international participants. To make the best use of the presence of the visiting scholars, it was preceded by a day-long Tutorial School on Low Energy Nuclear Reactions at IIT Madras. Also, a post-conference workshop on behaviour of metals was conducted. Four years later, he resumed his efforts and persuaded working scientists in the field of LENR to contribute over 30 papers to a special section that was published in *Current Science* in February 2015.

He ceaselessly tried to motivate a number of institutions in India to conduct LENR experiments by establishing the LENR-India Forum. He hoped this would attract young people and even private industry to the field. The 3rd LENR-India discussion forum meeting was jointly organized by NETRA, R&D wing of NTPC Ltd and National Institute of Advanced Studies (NIAS) in Bengaluru on March 2016. It drew over a dozen research groups from various universities and other institutions that were interested in undertaking R&D in LENR. Hopefully, his loss would not discourage them in continuing their R&D.

Whether in neutron physics or in LENR, Srinivasan demonstrated his ability to get a large group of his colleagues from other divisions of BARC and from various other institutions in the country to work on related projects. This was possible because he could establish *guanxi* with many friends who were willing to help him. He believed that with its deep focus and capability in materials science, particularly metallurgy, and on nuclear engineering, and it is almost singular need for cheap, safe, reliable and sustainable energy with few alternatives available, India has a special place and need to harness LENR as a possible energy source. He dedicated his life after the career in BARC wholly to this end. His scientific publications post-retirement exceed those during his service in BARC.

A colourful, outgoing personality, Srinivasan did not confine himself to nuclear and neutron physics wholly, but was willing to explore other quasi-science fields as well. Perhaps it was the influence of his early education in Besant Theosophical Society School in Chennai. The theosophist in him led to his interest in unexplained phenomena like Occult Science of Annie Besant, global meditation and theophysics also known as Intelligent Design. As a member of the Theosophical Society and subsequently President of the Theosophical Order of Service (TOS) in India, he gave many lectures there. He is the author of a book titled *Introduction to Occult Chemistry – The Amazing Phenomenon of Extrasensory Perception of Nuclear Structure and Subatomic Particles*.

Though his professional life was woven around nuclear science and technology, he was drawn towards energy sources with least environmental impact like solar power and cold fusion. Two years before his demise, he gathered many scientists around him to begin a concerted effort to sensitize decision makers in the country on the hazards of millimeter waves used in 5G technology and did succeed in the attempt. Before he could pursue it further cancer took him on 31 August 2020, at the age of 83. In his demise, experimental nuclear physics and in particular the LENR field in India has lost an enthusiastic supporter who led from the front.

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