A checklist for higher education

C. N. R. Rao, as the Chairman of the Science Advisory Council to the Prime Minister of India, has submitted a document to the Ministry of Human Resource Development (MHRD), Government of India, raising concerns over the state of higher education and a checklist for its progress. The document titled 'Essential Steps for Progress in Higher Education: A Check-list' enumerates 10 key steps that, if adopted, will transform higher education enabling India to compete with neighbouring countries such as China.

Over the years India has increased its investment in science and higher education. In a vision document titled *India as a Global Leader in Science* in 2010, Rao had advised an increase in science funding up to 2.5% of GNP by 2020.

Number of students aiming for higher education is likely to increase in the next few decades. New IITs and IISERs are being created that will absorb some of these numbers. But when a greater number of students pass out in the same field the employment opportunities get narrowed down. The first element of the 2011 document is thus a recommendation for forming a group that estimates the manpower situation 20 years from now. This is to ensure that young people have various alternative career options outside mainstream science and engineering.

According to the document, 10 higher education institutions need to be identified and provided enough support for enhancing their competencies. Presently, India's institutions do not rank anywhere near the top institutions in world's ranking. The document also calls for a greater support in science and higher education from the States.

Considering that the examination system is in shambles, the document proposes a reform in the entire examination system, including entrance, selection, qualifying and final examinations. It suggests to have a single national examination system for admission to higher education institutions, like the GRE in the United States. The document also demands an overhaul in the administration of the education system and refers to it as an urgent need. It also lays emphasis on improving teaching standards in the country and on harvesting talent of the young in rural India. It suggests nurturing inter-institutional collaborations, both within the country and at an international level.

Other issues voiced are the increasing number of government colleges and universities, curricula for basic and specialized courses, rating of institutions, criteria for the appointment of vice-chancellors and directors, and loss of creativity among the young due to the examination and reward system. The document suggests that a task force be created by MHRD to look into these issues and to come up with a vision document laying a roadmap for higher education in the country.

Richa Malhotra

The design of an advanced nuclear reactor

Srikumar Banerjee speaking at IISc, Bangalore.

Ramaseshan and Banerjee are two of India's distinguished materials scientists. While Ramaseshan's expertise contributed to the development of the Chitra–TTK heart valve, Banerjee's work on zirconium alloys had applications in the development of pressure tubes for the Indian pressurized heavy water reactors. Srikumar Banerjee (Secretary to Government of India, Department of Atomic Energy and Chairman of the Atomic Energy Commission) delivered the S. Ramaseshan Memorial Lecture at the Indian Institute of Science, Bangalore on 29 April 2011. His topic 'How the design of an advanced nuclear reactor evolves?' is extremely relevant today in the context of the disaster at Fukushima and the debate on whether India should continue with nuclear power.

Banerjee pointed out that hundreds of people work for 20 years on the drawing board to design a nuclear reactor. The design involves multidisciplinary inputs from fields such as reactor physics and thermal hydraulics, and has also to be verified.

The source of energy in a reactor is nuclear fission. The energy released by fission of 1 g of uranium-235 is 1 MW-day of energy. To release the same amount of energy, 3 tonnes of coal would be required. The neutrons released in fission interact with other uranium nuclei and an uncontrolled chain reaction could ensue, with the possibility of an explosion. This can be avoided if the chain reaction is controlled through a 'neutron absorption' process which artificially removes the excess neutrons from the system. The job of a nuclear physicist is to evaluate the spatial and temporal distribution of neutron flux, i.e. the distribution of the nuclear fission energy.

Only one fissionable nucleus exists in nature – uranium-235. The other possible fissionable nuclei are plutonium-239 (obtained from uranium-238) and uranium-233 (obtained from thorium-232). In India, there are limited resources of uranium (~150,000 tonnes, only a part of which can be converted to fuel) and large reserves of thorium (~225,000 tonnes, the whole of which can be converted to fuel).

The main components of a nuclear reactor are: (i) fuel: the material containing the isotope that is fissioned, e.g. natural thorium, plutonium and thorium-based fuels; (ii) coolant: the medium that is employed to carry away the heat generated by nuclear fission from the fuel, e.g. light water, heavy water, sodium, lead and its alloys; (iii) moderator: the medium that reduces the energy level of neutron to thermal levels, e.g. light water, heavy water, graphite and beryllia; (iv) reflector: the medium, surrounding the moderator, that enhances the neutron flux within the reactor by reducing leakage, e.g. light water, heavy water, graphite and beryllia; and (v) control device: the device that is used to control the neutron flux within the reactor containing, for example, boron-based and cadmium-based materials.

In a homogenous reactor, the fuel, coolant, moderator and reflector are uniformly mixed whereas in a heterogeneous reactor, the fuel is physically segregated from the coolant, moderator and reflector. Commercial reactors are of the heterogeneous type.

The reactor at Fukushima is a boiling water reactor (BWR). Banerjee described the salient features of this reactor as well as the pressurized water reactor (PWR) and the pressurized heavy water reactor (PHWR). Both PWR and BWR use light water as a coolant and are vessel type reactors, whereas PHWR uses heavy water for cooling and is a tube type reactor. In PHWR, high pressure coolant and fuel are kept inside pressure tubes. In PWR and PHWR, the water is kept at a pressure that prevents boiling and steam is generated in the secondary side of the steam generator whereas in BWR, water is allowed to boil and steam is generated in the core of the reactor and goes directly to the turbine. The power of a nuclear reactor does not depend on the amount of fissionable material but on the rate at which heat can be extracted from it.

Banerjee also explained the nuclear fuel cycle which includes the mining of uranium and thorium, refinement through chemical processing, conversion to fuel and fabrication, use in nuclear power plants and cooling of the spent fuel. This spent fuel can be reprocessed and used again as recycled fuel or has to be disposed. In India, the quantum of waste generated is small and there is no geological repository at present. A large sized engineered house exists underground to store the spent fuel and is continuously air cooled. This is an interim management strategy that can contain the waste for years but not centuries. When the quantity of waste becomes large, one option is to create a geological repository. The aim is to use a closed fuel cycle.

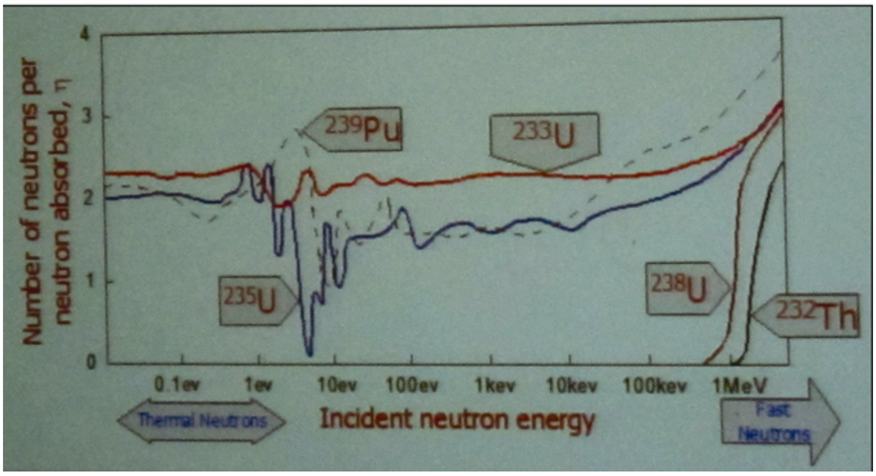

Figure 1. Fast neutrons for fast breeder reactors. (From the presentation by Banerjee).

The Indian nuclear power programme has three stages. The first stage involves natural uranium fuelled pressurized heavy water reactors, the second stage features fast breeder reactors utilizing plutonium-based fuel and the third stage includes advanced nuclear power systems for utilization of thorium (http://www.dae.gov.in/publ/3rdstage.pdf). Banerjee explained how the operation of PHWRs in the first stage results in the conversion of uranium-238 to plutonium. In the second stage, the generation of more plutonium than the amount used is possible by running a fast breeder reactor in the domain of fast neutrons (see Figure 1). For plutonium, the number of neutrons produced per fission is highest for high energy incoming neutrons.

The third stage has thorium in the centre. There are three stages here: (i) power generation primarily by PHWR building and fissile inventory for the next stage, (ii) expanding power programme and building uranium-233 inventory, and (iii) thorium utilization for sustainable power programme. This third stage plans to utilize uranium-233 along with thorium-232. Technologies are required for fuel fabrication, burning in the reactor and reprocessing the spent fuel. Many of these technologies have been developed on a semi-industrial scale over the years, for example, uranium-232 in PHWRs has been used for flux flattening. Design effort has been going on for many years on a novel reactor: using natural uranium as fuel with efficient use of uranium-235 per tonne mined, no requirement for a large pressure vessel, no stoppage of reactor for refuelling and excellent physics design with minimum amount of neutron loss.

The advanced heavy water reactor (AHWR) should incorporate the desirable features (such as high neutron economy, good fuel utilization, moderator as heat sink and on-line fuelling) and address the undesirable ones (such as positive void reactivity coefficient of coolant, low discharge burn-up and tritium problems with heavy water coolant), in the PHWR. Banerjee said that the discharge burn-up can be increased by using higher enrichments. The coolant void coefficient can be made negative by tuning the neutron spectrum to enhance resonance captures or by redistributing the thermal flux over the cluster.

The design ambitions for developing the specifications for a thorium fuelled technology demonstration reactor are: utilization of the technology already developed in the country, thorium utilization, online refuelling, passive systems such as natural circulation for heat removal during normal operating and shutdown conditions, light water coolant and negative void coefficient. In a passive system, there is no need for human intervention; even during a total blackout condition, cooling will go on. This reliability needs to be checked. Some specifications for a thorium fuelled reactor are: thorium-based fuel, heavy water moderated, light water cooled and vertical pressure tube type with boiling in the core. For this design, a close interaction between reactor physicists and thermal hydraulic experts is required. Banerjee discussed the evolution of the main heat transport system and the reactor physics design of AHWR, and the thorium fuel cycle development. A complete design of the AHWR with a design life of 100 years is now available. It incorporates a multi-tier safety system including a passive decay heat removal system by isolation condensers. Decay heat removal was a problem at Fukushima.

Banerjee also talked about the challenges in implementation of the advanced passive features in AHWR. These comprise: control on natural circulation flow instability, meeting the critical heat flux limits, start-up procedure, avoiding stratification in large pools, development of passive valves and passive containment isolation system. These challenges are addressed through a large experimental programme. The passive safety system encompasses a gravity driven water pool of 8000 m^3 and core cooling through natural circulation – these features were not provided in the Fukushima reactors. The civil engineering design of the building takes into account both static and dynamic loads during floods, earthquakes, aircraft impacts and tsunamis. Another challenge in the design is the optimization of the downcomer layout because thermal stress demands flexibility while seismic stress demands stiffness.

The validity of the fuel assembly and the containment design need to be tested. Major experimental facilities available for validation include the Integral Test Loop, Parallel Channel Loop and passive containment cooling facility. A critical facility to study neutronics is also available. Narrow gap welding is required if the design life has to be 100 years; how these welds behave under various stresses is also studied. Banerjee pointed out that AHWR is only a step towards the third stage programme and itself is not the third stage programme.

Geethanjali Monto (*S. Ramaseshan Fellow*). e-mail: geethum@hotmail.com