"There is a need for constant interplay between basic sciences, technology and industrial practice if economic progress is to result from the activity undertaken"

Vikram Sarabhai

Vision of the three stage Nuclear Power programme enunciated by Dr. Bhabha, laid the foundation for nuclear power development in the country. The first stage comprises setting up of Pressurised Heavy Water Reactors (PHWR). Fast Breeder Reactors (FBR) which form the second stage, use plutonium based fuels surrounded by depleted uranium blanket to produce more plutonium and enhance nuclear capacity and produce further plutonium. The third stage would comprise uranium233 based thermal reactors to produce power and also efficiently convert thorium232 to uranium233. The third stage will utilise the vast reserves of thorium available in the country, towards meeting large energy demands essential for high pace economic growth trajectory of India.

Fast Breeder Test Reactor (FBTR) heralded India’s entry to the second stage of the nuclear power programme. FBTR the flagship of the Indira Gandhi Centre for Atomic Research (IGC Newsletter Vol. 61, July 2004) is not only a test reactor for development of advanced fuels and structural materials, but also a power demonstration reactor. (IGCAR Newsletter Vol. 62, October 2004). It is a synergy of many disciplines that has resulted in the success of FBTR and enabled launching of 500MWe Prototype Fast Breeder Reactor (PFBR) in 2003 (IGC News Letter Vol.69, July 2006). In this article, I will be discussing some aspects of Fast Reactor Technology Development, not
covered in the earlier essays on Fast Reactor Science and Technology, which have appeared in IGC newsletter.

**BIRTH OF REL**

Towards engineering development for sodium cooled Fast Reactors, the design of a 500 kW sodium facility was initiated in 1968. S/Shri M.C. Sabherwal and A. Venkateswarlu, engineers trained in sodium technology abroad were associated with the design. The construction of this facility was undertaken at Kalpakkam under the guidance of Shri. A. Venkateswarlu initially, and later Shri R.D. Kale, who played the prime role in setting up the Reactor Engineering Laboratory (REL). The facility was setup with an electrical heat source, a sodium to sodium heat exchanger, a mechanical sodium pump and a sodium to air cooler. The design, construction and operation of this facility has given a good insight into heat transfer aspects, detection and handling of sodium leaks besides training manpower for FBTR operation. A sodium purification loop was also set up to treat three tons of commercial grade sodium from indigenous supplier for use in the facility. Sodium of reactor grade was obtained by removing impurities by means of circulating sodium through a cold trap. Shri. R. Subramanian supported by Shri. M. Rajan was responsible for this activity, which provided the base for setting up a large scale purification facility for FBTR.

**SUPPORT TO FBTR**

Right from its inception the focus of REL, was towards providing inputs for successful commissioning and operation of FBTR. The working team comprised young, enthusiastic engineers from the training school viz. S/Shri. K. Swaminathan, Late R. Selvaraj, R. Prabhakar, M. Rajan, K. Balachander, K.K. Rajan and a good number of scientific assistants and tradesmen, all trying their hands on a new technology. Development of Rupture Disc for use as safety device against over pressure in the FBTR Steam Generator was a challenge. A task force under the leadership of Shri. S.C. Chetal took up the challenge and finally a rupture disc with 5 milli seconds response time was developed, tested in house and used in FBTR. This is an example of technology denied serving as a motivator for developing technology. Development of flat linear induction pump, electromagnetic flowmeters, eddy current flowmeter and sensitive sodium ionization type leak detectors etc. were relentlessly pursued by the team. Mastering of purification technology in the earlier years, led to successful purification of 150 tonne of commercial grade sodium into reactor grade and its transportation to FBTR in batches.

**THERMAL HYDRAULIC ANALYSIS**

Towards thermal hydraulic analysis for FBTR, the Reactor Operation Studies team, under the leadership of Shri. G. Vaidyanathan developed the indigenous computer codes for steady state operation, plant dynamics from reactor to steam water system and process design of once through steam Generators used in FBR’s. The programmes were written in such a modular fashion, that in the 80s, the same codes with minor modifications for Pool type reactor assembly could be used for Prototype Fast Breeder Reactor. Later, during tests done at FBTR, it was noted that the measured data matched closely with the predictions. Having gained confidence in developing 1D codes, the team embarked upon development of 2D and 3D computer codes.

The thermal hydraulic analysis of FBTR with the core cover plate mechanism stuck in a higher position than normal was carried out with 2D and 3D computer codes. The results matched closely with measured data and gave confidence to the regulatory authorities to clear operation under changed conditions.

The analysis expertise developed at IGCAR has also benefited the PHWR programme. One example is the evaluation of the flow and temperature patterns in the moderator system of MAPS reactor at Kalpakkam, after the manifold failure. Based on the findings
MAPS was restarted and went up to a maximum of 50% power, as a part of short term rehabilitation works carried out under the able and enthusiastic leadership of Dr. Anil Kakodkar, the then Associate Director (Reactor Group), BARC and present Chairman, AEC. Later, the power was raised in steps and full power reached after addition of spargers in the moderator system.

**PFBR R&D APPROACH**

It was abundantly clear, that the realization of PFBR necessitated a lot of engineering rigs and large scale experiments in water and sodium. Experiments in sodium are complex, time consuming and costly. So the approach has been to carry out experiments with similitude coolants like water and air for the hydraulics aspects. The judicious mix of analysis and experimental approach, has provided insight into the processes governing the mechanical and thermal loading. It would not be out of place to say that the marriage of advanced computations with experiments has created a comprehensive capability in solving many thermal hydraulic problems at this Centre.

**SODIUM PUMP**

The development of large circulating sodium pumps of centrifugal type for PFBR was a challenging task, taken up in collaboration with industry, under the leadership of Shri. R.D. Kale. The first phase in this programme dealt with the development of the sub-assemblies of the pump such as hydraulic model study, manufacture of special stainless steel castings, pump shaft and so on. The second phase consisted of building a full scale prototype and its performance tests. Meanwhile, a parallel effort made at IGCAR towards gaining insight into pump design and construction experience, resulted in the indigenous construction of a small capacity pump (50 m³/h). Cavitation performance of the pump was studied and the pump was also subjected to a short-term endurance test in 500 kW sodium facility. Fabrication of long stainless steel shaft (7.2m) for the PFBR pump was an engineering marvel, consisting of a central hollow portion welded to two solid sections at ends, needing accurate finish machining. Visual cavitation tests were performed on the model pump fitted with transparent (Perspex) suction casing. Greater challenge was faced, when the overall size had to be reduced from economic considerations. A new scale model was fabricated and paint erosion test devised to verify absence of cavitation. This work was executed successfully, with IGCAR and the industrial partner M/s Kirloskar Brothers acting as a team from design to completion of testing.

**INTERMEDIATE HEAT EXCHANGER**

The Intermediate Heat Exchanger (IHX) is another important component requiring robust design and validation. Studies, in the 500 kW facility had given insight into the heat transfer process. As a prelude to the testing of IHX for Flow Induced Vibration (FIV), measurements were carried out on a three tube model. Natural frequency and mode shapes were determined and these matched well with theoretical predictions. Flow induced vibration test of IHX sector in water, with instrumented tubes, fixed with strain gauges and accelerometers, qualified the design.

**POOL THERMAL HYDRAULICS**

In a pool type reactor of PFBR type, complex flow and temperature patterns exist under different operating conditions. In this direction, thermal hydraulic studies have been completed in three scale models to cover the range of similitude parameters. Thermal stratification studies simulating hot pool conditions after a reactor scram were conducted. Further a large 1/4 scale model of reactor assembly thermal hydraulics (SAMRAT), with large sized components, has been built and a variety of experiments on velocity and flow distribution, thermal stratification, free level fluctuations and gas entrainment have been conducted. Experiments conducted with circumferential baffles on inner vessel have shown their effectiveness in decreasing gas entrainment at free level. The data obtained have been
very important in qualifying the layout of the hot pool design of PFBR.

**CORE SUBASSEMBLY HYDRAULICS**

A water rig to test full scale subassemblies of fuel, blanket, reflector etc. besides testing of orifices and labyrinths has been set up. It has helped in the pressure drop and cavitation testing of multihole and honey comb orifices for fuel subassemblies and labyrinths for the grid plate-assembly foot gaps. Flow induced vibration measurements on a 19 pin bundle model of the PFBR fuel subassembly and other measurements have validated the numerical model used.

**MAIN VESSEL BAFFLE VIBRATION**

As part of experimental flow induced vibration studies on main vessel cooling baffles, natural frequency and damping measurements were completed on baffles made of aluminum and stainless steel in scale models. The study was prompted by the observation of main vessel cooling baffle vibration in Super Phenix reactor in France. The experiment have given a good insight to the process and qualified the design.

**GRID PLATE HYDRAULICS**

Hydraulic experiments on scale model of PFBR grid plate, in air, were completed in collaboration with Fluid Control Research Institute, Palakkad, Kerala. The objectives of the experiments were to study the flow and pressure distribution at different operating conditions and to select an optimum baffle plate configuration. The setup also gave confidence to the fact that core would not starve of adequate flow during rupture of one of the inlet pipes.

**SODIUM EXPERIMENTS**

Long duration experiments (4000h) have been conducted to determine sodium mist transfer through the vertical annuli present in the bellowsless Control and Safety Rod Drive Mechanism (CSRDM), a concept studied for PFBR. This concept has the advantage, accruing from the elimination of the stainless steel bellows which are known to have limited life. The studies have confirmed the use of bellowsless concept. Circumferential temperature asymmetry and sodium aerosol deposition in vertical annuli of top shields have been experimentally studied in a small mockup and in a large diameter test vessel in Large Component Test Rig (LCTR). These tests have validated our predictions and provided us with a physical understanding of the effect of different convection barriers and operation parameters.

**STEAM GENERATOR EXPERIMENTS**

Steam Generator(SG) is an important component deciding the plant availability and is referred to as Achilles heel of FBR. Many important studies were therefore directed towards this component. Experimental study was carried out in water, on the scale model of the inlet plenum of PFBR steam generator to ensure uniform flow at the entry of tube bundle using different devices. A 60deg. sector model of PFBR steam generator was tested in water for velocity measurements in the inlet plenum and flow induced vibration of tubes. The tests have confirmed our predictions. An experimental rig was commissioned for studying detection of simulated steam generator leaks by acoustic technique. Steam leak signal data received from IAEA for developing noise analysis technique to detect and localize the leak source were analyzed using in-house developed methods. During the 8 MW(t) power operation of FBTR, acoustic noise measurements were carried out on one steam generator module with argon injection and the response of the acoustic transducers was measured. This technique is being improved further to detect onset of water leak in SG.

The Mass Transfer loop has been used to study carbon transfer from the ferritic steel used in SG to the austenitic stainless steel in rest of the secondary sodium system. The BIM loop has been successfully used to study the
bimetallic weld between 2.25Cr-1Mo and Stainless steel 316. The SOWART rig has been used for micro water leak studies in SG and is being used to get further data on material wastage due to larger leaks. The rig has also been useful to evaluate different Hydrogen sensors in sodium and argon cover gas. These are essential to detect onset of a sodium water reaction in SG.

With a view to reduce conservatism in design for future FBR steam generators and arrive at an economic design, a 5.5 MWt steam generator test facility has been set up. This simulates the operating parameters of PFBR. Temperature measurements across the height of the tubes in different rows and at steam outlet of tubes give a measure of the performance and give data to tune the predictive tools.

**UNDER SODIUM VIEWING**

Sodium is opaque to light. However, ultrasonic technique enables us to see through liquid sodium and identify or detect objects kept under sodium. Ultrasonic method was utilized for viewing under sodium in FBTR reactor vessel. The device is particularly useful in scanning the under-space below the core cover plate to detect any projecting subassembly, the complete operation being controlled through a microcomputer. The ultrasonic viewer also gave an indication of the maximum displacement of the bent guide tube, after the fuel handling incident in FBTR. Ultrasonic transducers suitable for immersion in liquid sodium up to a temperature of 473K (200°C) have been developed.

**MAGNETIC SENSORS**

Electromagnetic flowmeters have been developed and more than 36 flow meters in 12mm to 100mm pipe sizes have been successfully manufactured and tested to achieve robustness of the components. Eddy current flow meters, to measure sodium flow through fuel sub-assemblies, have been successfully developed and perfected after testing in FBTR.

Development of Curie point magnetic switch was started with a multi-disciplinary task force and has resulted in deciding, the correct material composition of the switch after extensive investigations and iterative experiments.

**SODIUM SPECIFIC INSTRUMENTS**

Sodium level measurement in different capacities are measured continuously by sensors working on the principle of mutual inductance. This technology has been successfully transferred to Industry.

Sodium leak detectors are required to detect even a minute amount of sodium leak, for the safe operation of the rigs and the reactors. Wire type, spark plug type and mutual inductance type detectors have been developed and tested. Sodium ionization detectors (SID) for detecting minute amount of sodium leak, from the pipelines and vessels of the sodium rigs have been developed. These can detect, as low a quantity as a nano gram of sodium in a cubic cm of the carrier gas. The testing of the sensors have been conducted in the SILVERINA loop. It can be said that the SID developed is comparable to International Benchmarks.

**SODIUM REMOVAL**

The components in sodium systems need to be cleaned free of sodium before attempting their repair, reuse or dismantling. Various cleaning techniques have been developed for different components. Alcohol dissolution has been employed for small and delicate components like valves, bellows etc. Large components such as sodium pump, heat exchangers etc. are cleaned by water vapour-CO₂ in inert gas atmosphere.

**SODIUM FACILITIES**

Over the years, the Fast Reactor Technology Group at the centre has acquired considerable experience in the design, construction and operation of sodium facilities, decontamination of sodium components, disposal of sodium waste and sodium fire fighting.
Reaction Test Rig (SOWART), Large Component Test Rig (LCTR) and Steam Generator Test Facility (SGTF). Testing Control & Safety & Diverse safety rod mechanisms, Fuel Handling machines viz. Transfer Arm & Inclined Fuel Transfer Machine (Full Size), and heat & mass transfer studies in cover gas are being conducted in LCTR. A 2 MWt Sodium to Air Exchanger, geometrically similar to that in PFBR, has been successfully tested for heat transfer performance, in SGTF. Also an eddy current inspection tool developed for ISI in SG by the Inspection Technology Group has been tested satisfactorily in SGTF, confirming its utility for PFBR. This facility will also serve as a training ground for PFBR steam Water System operation. The operation experience gained so far from all the sodium rigs has provided valuable inputs for PFBR design and operation. It can be said with high confidence that, we have a team of engineers who are able to design, build and operate sodium systems with a high level of confidence and maturity.

SAFETY

In the event of unlikely sodium fire, the same is extinguished with fire extinguishers containing Dry chemical powder (DCP). To take care of large leaks from components and piping, leak-collection-trays comprising corrugated shape cover with precise entry holes, working on the principle of self extinction by oxygen starvation have been developed and tested.

IN PERSPECTIVE

The growth of engineering development can be gauged from the fact that starting as a Development Section in 1969 with few engineers, today it has become Fast Reactor Technology Group with 300 personnel, its work encompassing all important engineering facets of sodium technology. Human Resource Development has been an important hallmark of this group. It has provided leaders to the other programmes of IGCAR. Shri. K. Balachander after two decades experience, became Head, Central Workshop and later the Regional Director of Directorate of Purchase & Stores at Chennai. Shri. R. Prabhakar after a stint of three decades in the group is presently Director (Technical) in BHAVIN. Shri. N. Vijayan Varier who provided the mechanical design & construction support for sodium rigs for 25 years is presently the centre’s Quality Assurance wing leader at Mumbai. Shri. A.S.L.K. Rao who was responsible for Sodium Pump design, after a stint of 28 years in the group, is now Head of Central workshop. Last but not the least Shri. M. Rajan after 32 years stint in sodium technology is now the Director, Safety Group at the centre. The group has also been responsive to accept personnel from other groups. Shri. P. Kalyanasundaram after a 30 year experience in Non Destructive Testing is now a part of this group, bringing in his rich experience in condition monitoring, noise analysis and digital signal processing. These changes have led to good crossbreeding of technical ideas and approaches. This has really benefitted the group and department.

Engineering development for Sodium cooled Fast Breeder Reactors has come a long way from its inception in 1970s. Comprehensive expertise has been built up for design and testing of a large number of components. Sodium Handling has become a common affair. Many sensors and related electronics for sodium have been made, tested and technology transferred to industry. The future direction would lie in experiments on large scale models of components with better measurement techniques, which could eventually lead to reduce conservatism in the design. Use of acoustic techniques, improvement in ultrasonic under sodium detection, improved hydrogen meters, development of Integral cold trap for Pool type reactors would also be pursued. The engineering development and testing capability has made a strong base and with this base, achievement of our enhanced goals on Fast Reactors will be a reality.

(Baldev Raj)