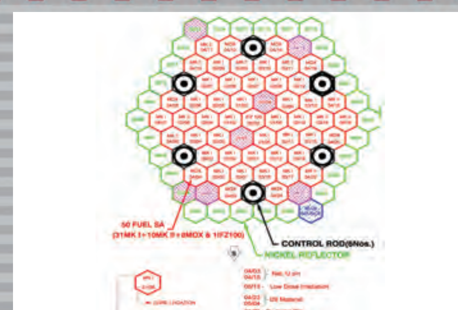
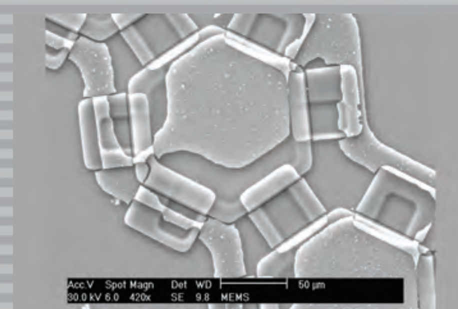
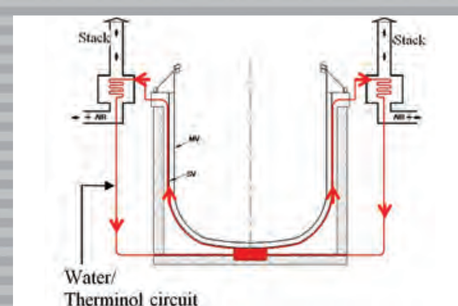
ISSN 0972-5741 Volume 106 October 2015

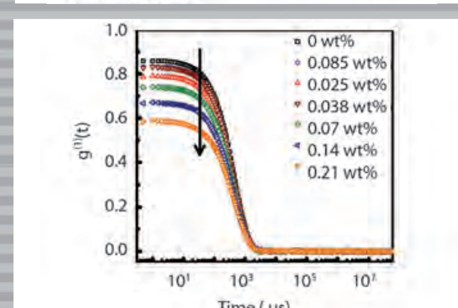
IGC Newsletter

IN THIS ISSUE









INDIRA GANDHI CENTRE FOR ATOMIC RESEARCH
http://www.igcar.gov.in/lis/nl106/igc106.pdf

From the Editor

Dear Reader

It is my pleasant privilege to forward a copy of the latest issue of IGC Newsletter (Volume 106, October 2015 issue).

This is the first issue being brought out after Dr. S.A.V. Satya Murty has taken over as Director, IGCAR and GSO.

Shri K. V. Suresh Kumar has highlighted the achievement of thirty years of successful operation of Fast Breeder Test Reactor, with unique high plutonium fuel.

Dr. Jayapandian has shared his experience on the design, fabrication and characterization of indigenously developed cMUT devices and has detailed about the failure analysis of these devices at various fabrication steps in the second technical article.

This issue's Young Officer's Forum features an article by Shri Anurag Samantara.

Shri V. Mahendran has shared his excitement in probing the competitive displacement adsorption of casein at oil-in-water interface using equilibrium force distance measurements in the Young Researcher's Forum.

We had distinguished visitors to our Centre in the last quarter including, Dr. R. Chidambaram, Dr. Anil Kakodkar, Dr. Baldev Raj, Dr. C. Ganguly, Prof. Riccardo Fenici and Prof. M.O. Garg.

Honourable Minister Dr. Jitendra Singh visited our Centre and other DAE Units at Kalpakkam.

We are happy to share with you the awards, honours and distinctions earned by our colleagues.

We look forward to your comments, continued guidance and support.

With my best wishes and personal regards,

M. Saibaba

(M. Sai Baba)
Chairman, Editorial Committee, IGC Newsletter
&
Associate Director, Resources Management Group

Our New Director

Dr.P.R.Vasudeva Rao greets Dr.S.A.V.Satya Murty on his assumption of charge as Director, IGCAR

Dr. S. A. V. Satya Murty, Distinguished Scientist and Director, Electronics, Instrumentation and Radiological Safety Group has taken over as Director, Indira Gandhi Centre for Atomic Research. He is from the 21st Batch of Training School and is a Homi Bhabha awardee. Dr. S. A. V. Satya Murty has made pivotal contributions in establishing efficient computer network, highend computer systems, unique facilities like, PFBR Operator Training Simulator and Advanced Visualization Centre at IGCAR. His work on Wireless Sensor Networks has gained international recognition and he is coordinating one of the IAEA projects aiming at enhancing the application of wireless sensor networks in the nuclear reactor domain. He is also piloting the development of Time Domain Electro Magnetic System, which enables efficient method for identifying uranium mineral sources in the Country. He has several research publications to his credit and is on the editorial board of five Journals. He is a gold medallist from Jawaharlal Nehru Technological University and obtained his Doctorate from Homi Bhabha National Institute.

Director's Desk

I feel greatly honoured and consider it as a huge responsibility to steer this internationally renowned R&D establishment of the Department of Atomic Energy. It also gives me very humble feeling considering the eminence of my predecessors who have occupied this distinguished position. I will strive hard relentlessly and try to bring laurels to this great Organization & Department.

Our Centre is focussed on pioneering research in the domain of Fast Reactors and associated closed fuel cycle technologies which forms part of the second stage of nuclear programme as envisaged by our founder father, Dr. Homi Jehangir Bhabha. The R&D being pursued by the Centre focuses on realizing the mission programme and related basic research in project mode and this keeps us excited all the while. All our mission based and other research activities have to be pursued on very stringent time scales and with the excellence our Centre is known for. Anything not delivered on time has no relevance.

It is heartening that the Fast Breeder Test Reactor, the flagship of the Centre, is performing well and has successfully completed 30 years of operation. The reactor is licensed for operation upto 2018 and our efforts would be to extend it beyond and extend its utility by continuing to operate in a campaign mode. Our efforts also would be directed to operate this reactor at its full rated power of 40 MWt. Being a test bed for a wide variety of fuels, materials, irradiation experiments to qualify newer fuels should be on our top most agenda.

Providing all the suport to BHAVINI towards the early commissioning of the Prototype Fast Breeder Reactor is our top most priority. While the national and international communities are eagerly awaiting the criticality of PFBRs and generation of its rated power, we know that it will signal our strategy for future development of FBRs. We should quickly march forward towards completing the design of 600 MWe FBR 1 & 2, which would be constructed by BHAVINI at Kalpakkam. We have a great task ahead in completing the preliminary design by the end of January 2016 and work on the detailed design then on.

KAMINI is continuing to provide important services towards neutron radiography of Pyro devices for Space programme. We shall continue to operate it successfully and enhance its utility for providing support to diverse R&D programmes of the Department and the Country.

The design of Metal Fuelled Fast Reactors is an important area of IGCAR's vision towards reducing the breeding time and generating more fuel even in shorter time. This is essential to make Fast Reactors contribute higher share of nuclear power as envisioned by our Department. We should strive to design, construct and operate the 100 MWt experimental metallic fuel based reactor by 2030. This shall become operational by the time FBTR reaches its end of life. The success of the development of metallic fuel fabrication and designing, construction and operation of the experimental reactor and its fuel reprocessing would decide the pace of growth of Fast Reactors in our country. Hence our Centre has a greater responsibility to the Department and the country and I am sure the Centre will deliver on its promises.

CORAL has successfully completed 37 compaigns of reprocessing of spent FBTR fuel. Sincere and focussed efforts are afoot towards commissioning of the Demonstration Fast Reactor Fuel Reprocessing Plant soon. Again we shall work in project mode and commission the plant. The aqueous reprocessing of metallic fuels also needs to be demonstrated.

Fast Reactor Fuel Cycle Facility is an important project to the Centre and the Department towards achieving success of the Fast Reactor programme. Its early completion is essential for successful operation of PFBR and future FBRs coming up at Kalpakkam. Inspite of many challenges it is our duty to honour the envisaged time schedules by putting extra efforts and utilising all the expertise available in the Department. The whole Centre is committed to its early and successful commissioning.

Pyroprocessing, is yet another important milestone towards successful closing of the metallic fuel programme. I am happy at our success in the laboratory scale, but understand the responsibility towards fastening the pace for commissioning the engineering scale facility and early commissioning of DFMF. We shall also complete the design for Integrated Fuel Cycle Demonstration Facility at IGCAR on priority and get the project sanctions. Needless to say, complex design involves R&D support from all disciplines and I am confident that we would be able to achieve the same with the in-house expertise and support from peer groups of the Department.

Basic and applied research activities in the domains of material development, NDT, Wireless sensor networks etc. have set new international benchmarks, with several of our colleagues receiving ls for their knowledge and expertise. This encouragement drives us to set higher benchmarks and also widen the areas for attaining international acclaim especially in sensor development, robotics, remote handling etc.

We are in the process of finalising a Vision-2030 document for the Centre which would put forward strategies for marching ahead, based on the brain storming discussions amongst all the colleagues. I look forward to the document getting ready in the coming few months and expect all the activities of the Centre to be focused towards realising this vision.

I feel that while the Centre has had good number of collaborations with several academic, R&D institutions and industry, there is considerable scope for enhancing the same. In the domain of research publications, more efforts are required to realise the full R&D potential of our Centre. I look forward to seeing the results in the coming months.

The technical workforce of the Centre is toiling to fulfil our dreams with commitment which needs to be recognized and rewarded. Our Younger colleagues who have joined the organisation with lot of dreams and aspirations need to be nurtured with special care and encouraged to give in their best in meeting the schedules and challenges. They should be mentored towards expanding their talents. The senior colleagues have a responsibility towards them. Positive and constructive support from administration and accounts is helping us towards progressing in our scientific pursuits. All the efforts shall be continued to be made towards meeting the annual budget targets. The resources made available to us shall be put to optimum use.

All of us should continue to work as a family, complementing each others's strength and achieve the Centre's mission and vision of becoming the world leader in Fast reactor and associated closed fuel cycle technologies. I look forward to your active cooperation and support in discharging my responsibilities to the best of my ability.

S. A. V. Satya Murty
Director, IGCAR

FBTR - 30 Years of Successful Operation

Sodium cooled fast breeder reactors constitute the second stage of India's three-stage nuclear energy programme. FBTR is a 40 MWt, sodium cooled, loop type fast reactor and was built on the lines of the French Rapsodie-Fortissimo reactor, with modifications to make it a power generating plant (Figure 1). Its main aim is to provide experience in operation of the fast reactor, large scale sodium handling and to serve as a test bed for irradiation of fast reactor fuels and materials. Heat generated by fission in the reactor is removed by primary sodium loop and transferred to the secondary sodium loop. The secondary sodium loop is provided with once-through steam generator modules where the heat is transferred to a steam-water circuit consisting of feed water system and condensate system which produces super heated steam at a pressure of 125 bars and temperature of 480°C. The steam produced is supplied to a condensing turbine coupled to an alternator.

Stainless steel (SS 316) is the principal material of construction for the reactor core materials and coolant circuits. The choice of structural material is based upon fluence level or displacement per atom and irradiation damages like void swelling, irradiation embrittlement and irradiation creep effect. Based upon the above requirements, various materials like SS316L, SS316LN, D9, D9I and Ferritic–Martensitic steel were tested in reactor so far.

In test reactors, like FBTR where the core size is very small, fissile material content should be very high for achieving criticality. The fuel initially envisaged for FBTR was mixed oxide of uranium and plutonium with uranium enrichment upto 85%. Due to the difficulty in sourcing enriched uranium, mixed oxide with plutonium content of around 70% was subsequently considered. This fuel had some disadvantages with respect to fabrication, thermophysical properties and compatibility with coolant. Hence, unique mixed carbide with 70% plutonium carbide and 30% uranium carbide (called MK-I) was chosen and indigenously developed for FBTR. This fuel composition was being used for the first time in the world and the in-pile behaviour of this fuel was not known. The reactor achieved criticality with 22 carbide fuel sub assemblies in October 1985. Commissioning sequences of plant was done in four stages, such as low power operation without steam generator

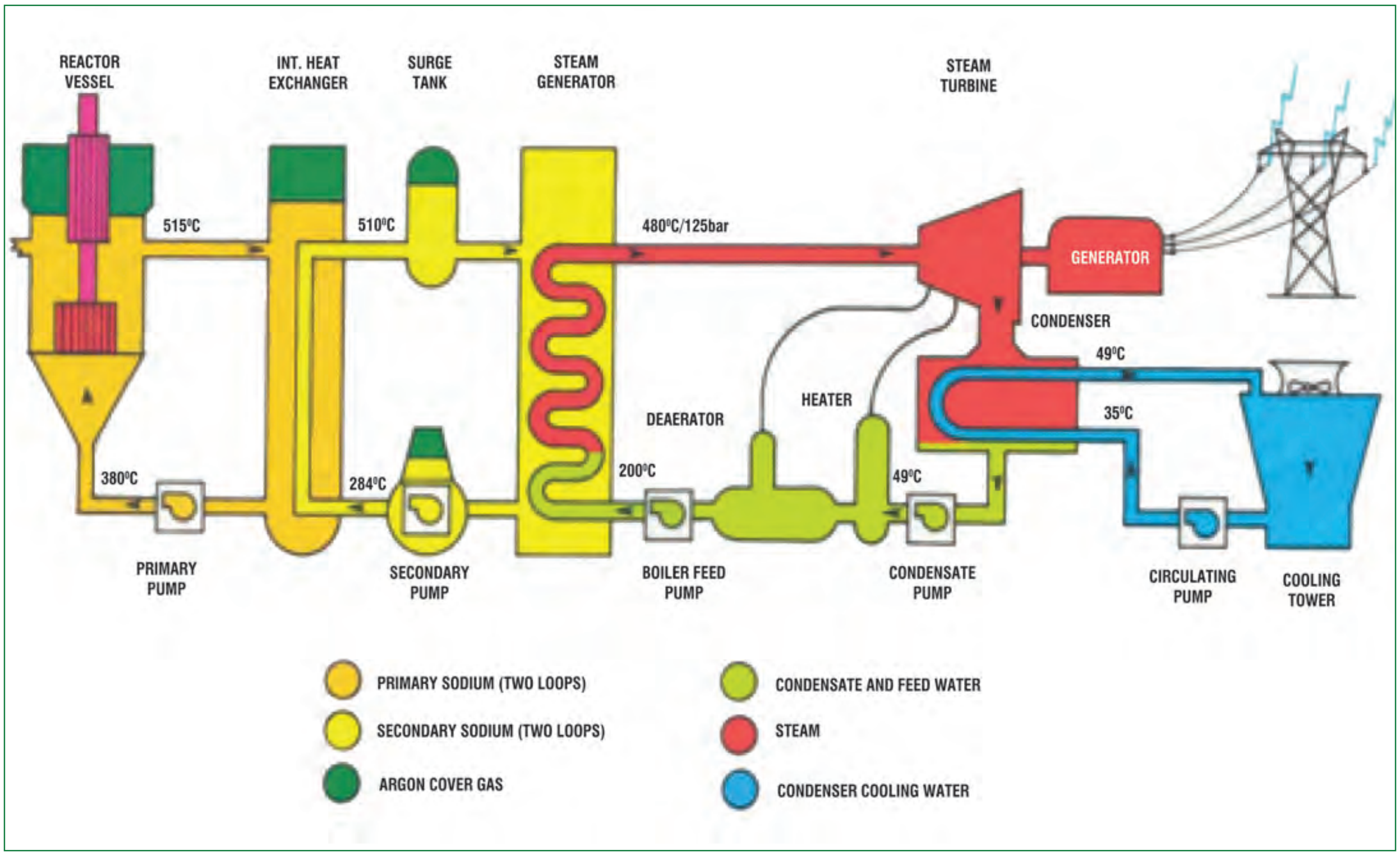


Figure 1: FBTR flow chart

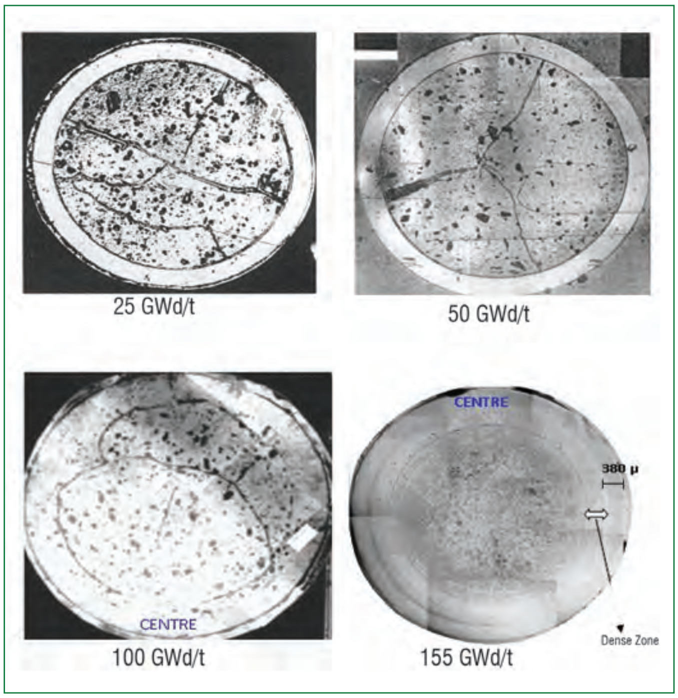


Figure 2: Fuel pin cross-section by PIE at different burnups

(1985),Operation with sodium on steam generator shell without valving-in water on the tube side (1986-90), power operation with water valved to steam generator (1993), operation with turbo-generator (1997) thereafter.

Initially, the fuel was rated for a Linear Heat Rating of 250 W/cm and the target burn-up was set at 25 GWd/t. The target burn-up had been progressively increased based on Post-irradiation examinations (PIE) at 25, 50, 100 & 155 GWd/t (Figure 2). In the light of the excellent performance of the carbide fuel based on Post-irradiation examinations, which has endured a burn-up of 155 GWd/t without any clad failure (one lead sub assembly upto 165 GWd/t), the core has been gradually expanded further by the addition of Mark-I (70% PuC- 30% UC) along with Mark-II (55% PuC-45% UC) and MOX (44% PuO_2-56% UO_2) fuel to compensate for the burn-up reactivity loss and replacement for burnt sub assemblies Mark-I (155 GWd/t) and Mark-II (100 GWd/t).The reactor power has been progressively raised from 10.6 MWt to a maximum of 24.5 MWt producing 5 MWe with reactor inlet temperature of 395°C and outlet of 490°C based upon evolution of core with respect to Linear Heat Rating limitation initially (320W/cm) upto 16th irradiation campaign and later with 400W/cm upto 23rd irradiation campaign, burnup limitation based on Post-irradiation examinations studies and fuel availability. A major modification i.e. isolation of three tubes out of seven tubes in each steam generator module (four numbers) was done to raise the system temperature close to design values reactor inlet/outlet temp (400/515 °C) with current constraints on core size and reactor power so as to conduct meaningful irradiation of materials and to study the performance of the systems at design temperatures was done at the end of 14th irradiation campaign.

FBTR has so far completed 23 irradiation campaigns in 30 years of operation. Presently, with a hybrid core of 31 Mark-I, 10 Mark-II and 8 MOX fuel sub assembly (Figure 3), 24th irradiation campaign is in progress for testing and validation of various fuels, irradiation of D9 & low dose structural materials like 304LN and 316LN, instruments and equipment which are of importance to India's Fast Reactor programme at high operating temperatures. It is currently operated on a mission mode for the irradiation of metallic fuels. Irradiation of PFBR test sub assembly upto 112 GWd/t based upon Cumulative Damage Fraction (CDF) value, TRISO coated particle with ZrO_2 kernels and disc specimens of Nb-1Zr-0.1C for High Temperature Gas Cooled Reactor, short term irradiation of the sphere-pac fuel pins and irradiation of ferro-boron shield material, were also completed for future developments. The reactor was also utilized for studying the irradiation creep behaviour of Zr-Nb, being used in the Indian Pressurized Heavy Water Reactors.

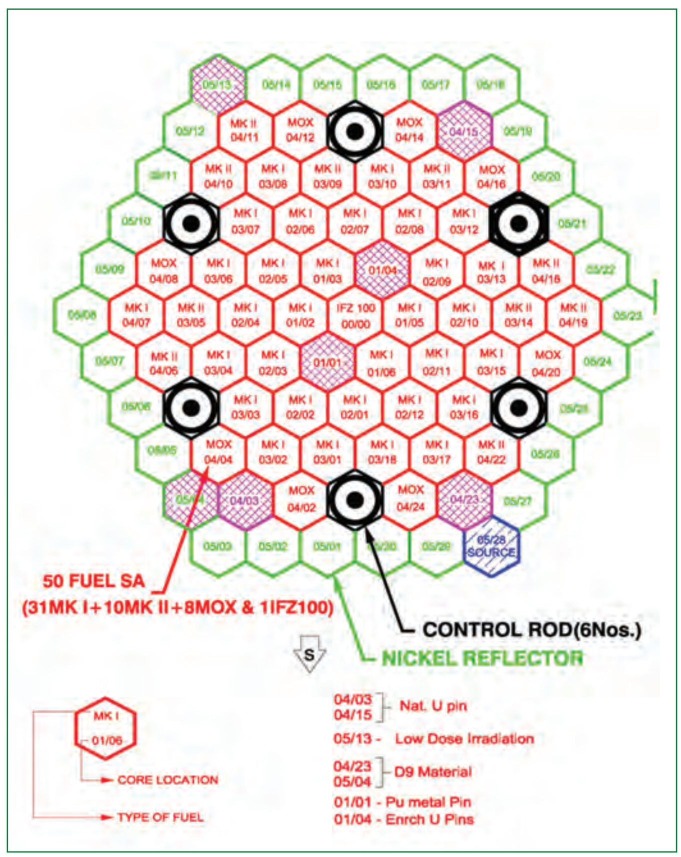


Figure 3: Core configuration for 23rd Campaign

The feasibility of production of Sr^{89}, a medical isotope used in bone cancer therapy, was demonstrated during the 15th campaign by irradiating Yttria.

Over the years, several safety related physics experiments have been conducted. These include, temperature and power coefficient measurements, sodium void coefficient measurements, reactor kinetics experiments, response of delayed neutron detection system to detect clad failure, flux mapping in sodium above core using foils, drop time measurements using Kalman filter technique, sub assemblies and control rod worth measurements, neutron detectors testing and experiments to validate the Failed Fuel Detection System. Several engineering tests also were carried out to validate the codes used in incident analysis like off-site power failure and tripping of one pump each in the primary, secondary or tertiary loops. Natural convection tests were carried out and the sequence of events confirmed to be as per safety logic. Primary pump coast down characteristics, take over by the batteries and low speed running of the pumps, were studied and found to be as per the design intent. Other tests like heat removal capability by Biological Shield Cooling (BSC) & Pre-Heating and Emergency Cooling (PHEC), Reactor Containment Building (RCB) leak test, steam generator instability test, concrete evolution test were checked and validated. The challenges faced during this thirty years of operation include a major fuel handling incident, primary sodium leak, reactivity transients and leak in biological shield cooling coils.

Sodium systems have been operating for the past thirty years and their performance has been excellent except for a few sodium bellow valve leak incidents. The sodium purity has been maintained consistently well for the past three decades by cold-trapping of oxides (impurity level < 0.6 ppm) and cover gas purity are also well maintained. The four sodium pumps have logged trouble free, cumulative operation of more than 8,00,000 hours. There were no incidents of oil leak from the pump seals to the sodium circuit so far. The steam generators, which operate with high pressure steam / water on the tube side and sodium on the shell side, have operated for 34,000 hours without any sodium-water reaction or sodium leak from the shell.

Two major modifications were carried out - one on the steam generator leak detection system and the other in the steam-water circuit. These helped in improving the campaign availability from less than 50% initially to more than 90%. Also several upgradation

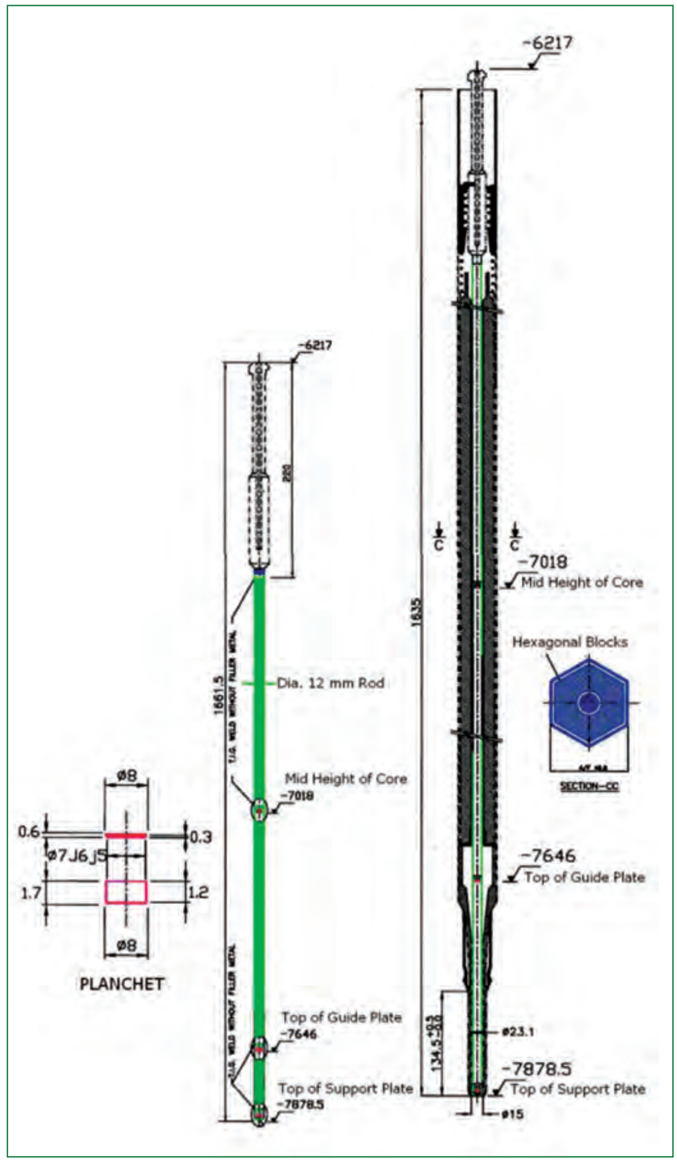


Figure 4: Special subassembly with capsule to measure the fast flux at the Grid Plate locations using Np foils.

and modifications were done in the plant, so as to improve the system reliability, safety, availability and operational convenience. All these modifications have gone a long way in improving the campaign availability factors to 90% in the recent campaigns.

The thermal energy generated taking into the cumulative value since first criticality is 483.48 GWh and the turbo generator has generated cumulatively 28.334 Million Units of electricity.

Experience with fuel handling was excellent except in one incident which took place during the early stages of FBTR operation. So far seventy nine campaigns were completed in handling various activities like replacement of all control rods and their outer sheaths, handling of failed fuel sub assembly, handling of various irradiation test capsules and sub assemblies and various decontamination activities. The reprocessing of the high burn-up carbide fuel has also been demonstrated by IGCAR and closing of fuel cycle has been successfully established.

The general radiation levels in all the accessible locations in reactor containment building during the operation of the reactor was very less and within the acceptable limits. During the last thirty years, total radioactivity released to the environment is ~ 0.03% of the limit set by regulatory authorities and there has been no significant event of any abnormal radioactivity release, personnel or area contamination, testifying to the fact that Fast Reactors are eco-friendly.

Various safety up gradation and plant life extension activities were carried out in the recent years, which included seismic re-evaluation, ageing management studies and Post Fukishima Studies. The plant life is governed by replaceable and non-replaceable components and the ageing factor is based on corrosion studies, creep - fatigue interaction, loss of ductility etc. All components were design checked for 2000 cycles of operation with an inlet temperature of 380 and outlet of 520˚C. But the significant thermal cycles is only 141 at a maximum differential temperature of 91°C and hot leg temperature of 482°C. The total number of high temperature operation is ~ 30000 hours as against the design life of 100000 hours. Hence there is no significant creep damage to the high temperature components. Life based on cumulative creep-fatigue damage has also been established in the design and found to meet the above creep life and fatigue cycles for all the components.

The main component limiting the life of the reactor is the grid plate, supporting the core. The fast flux at the grid plate was measured using Neptunium foils (Figure 4). The residual life of the grid plate is governed by limit on displacement per atom corresponding to 10% uniform elongation which works out to be 6.52 effective full power years. With a planned Annual Capacity Factor 50%, the reactor, can be operated up to 2024.Presently established displacement per atom limit is 4.37, where there is no concern in operating the reactor up to the tested limit of 2.827 displacement per atom i.e. 3.5 effective full power years. For a more realistic estimate, it is planned to irradiate further specimens at the current grid plate temperatures (~400˚C) up to about 7 displacement per atom.

Recent studies estimated that the revised flood levels of 12.01 meters under cyclonic condition combined with heavy precipitation & high tide with return period of 1000 years. Accordingly the height has been raised to 12.01 meters from the existing level of 11.5 meters. The flood level is estimated to be 12.896 meters taking into the consideration under worst case of Tsunami along with high tide with return period of 10000 years. To meet this requirement, flood gates are being provided up to 13 meters elevation at all entry points to Fast Breeder Test Reactor. As part of Fukushima retrofits, solar lamps were installed in and around FBTR. Layout and design of new flood safe DG building was frozen and conceptual design of supplementary control panel for any post Design Basis Accident events was finalized. Towards seismic retrofitting and easy fixes, anchoring of safety related panels and inter panel connections were completed for the most of the panels.

In the aftermath of Fukishima accident, a study of post decay heat removal aspect was carried out and various modifications / qualifications of the systems required to do their intended functions in detail were studied and the modification works are in progress. Also it is being proposed to install a strong motion accelerograph to monitor the ground movement which uses a tri-axial accelerometer and to measure upto 0.5 g for any seismic event taking place in and around FBTR for which a seismic alarm is planned to be provided.

Based on post Design Basis Accident events, studies were carried for decay heat removal by natural convection by opening the trap doors of steam generator. Total heat loss including the losses in pipelines from the system was found to be 980 kWt at 350˚C, which gives an extrapolated value of 2 MWt at 520˚C. Recent studies on extended black-out scenario indicate that the natural convection is sufficient to remove decay heat even if the steam generator trap doors are not opened and even after one year, there is no risk of freezing.

Based on satisfactory experience, operating license of FBTR was extended upto June 2018 on completion of review of Periodical Safety Review (PSR) by SARCOP.

The encouraging experience with FBTR operation has been a major factor in the launch of the 500 MW(e) Prototype Fast Breeder Reactor at Kalpakkam. This reactor has been designed and developed by IGCAR. With these, India is set to launch upon a major programme of fast reactors in the next decade.

Reported by
Shri K. V. Suresh Kumar and Colleagues
Reactor Operation & Maintenance Group

Indigenous Design, Fabrication, Failure Analysis and Characterization of cMUT Devices

Capacitive micromachined ultrasonic transducer (cMUT) is basically a parallel-plate capacitive micro structure with bottom electrode fixed on the substrate and top electrode on the suspended membrane, which can vibrate at ultrasonic frequency. It has proved to be a better alternative to piezoelectric ultrasonic transducers for various applications. cMUT is made directly on silicon wafers by means of standard micromachining techniques and potentially shows many attractive characteristics such as larger bandwidth, good capabilities to make high-frequency arrays, possibilities to integrate on the same wafer, the front-end electronics, and finally, low cost for mass production.

At IGCAR, a programme on the development and fabrication of cMUT was initiated in collaboration with Indian Institute of Science, Bengaluru and Central Electronics Engineering Research Institute (CEERI), Pilani. Design of cMUT devices was carried out at IISc and fabrication of cMUT was performed at CEERI, Pilani, using surface micromachining and wafer bonding techniques. IGCAR played a crucial role in device characterization and failure analysis making use of in-house characterization tools and in providing effective and useful feedbacks about the failure of fabricated devices. This article shares some of the experiences about the design, challenges during fabrication and failure analysis of these devices.

Device Description and Design

cMUT is a device with two plate-like electrodes of a capacitor, in micron dimensions, fabricated though standard IC fabrication process. During operation it is biased with a DC voltage and simultaneously driven with an AC signal to vibrate one of the plates. It can be used as both ultrasonic transmitter (electrostatic force is responsible for vibration in membrane to transmit the waves in surrounding medium) and as receiver (deflection of membrane due to pressure of ultrasonic waves, resulting in capacitance change).

Physical parameters of the cMUT were designed using Intellisuite

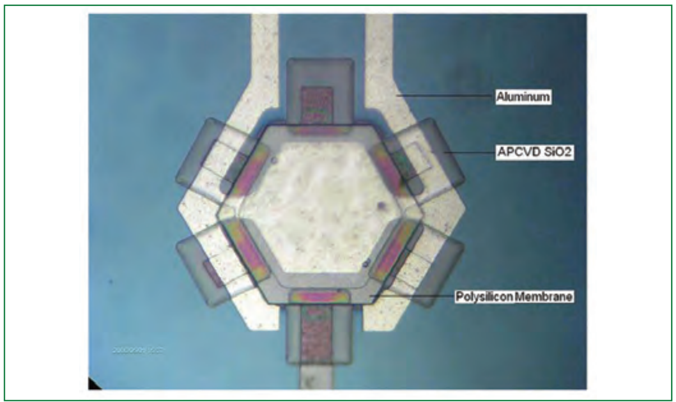


Figure 2: Single element of cMUT device with poly silicon membrane and aluminum coated top electrode.

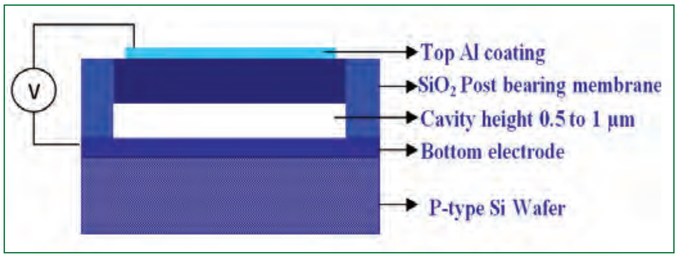


Figure 1. Schematic diagram of a single cMUT cell.

– a FEM (Finite Element Method) simulation tool. It was used to calculate membrane characteristics including maximum displacement, equivalent mechanical impedance and frequency response. The required input parameters for these simulations include thickness and radius of the membrane, Young's modulus, Poisson's ratio, material density, dielectric constant, environmental pressure, tension force, electrode thickness, air gap thickness, DC bias source, AC signal and ratio of AC to DC voltages. The shape of the silicon membrane was regular hexagon with an edge length of 50 μm and thickness of 1 μm. On top surface, Al electrode was selected with a dimension of 40 μm edge length and 1 μm in thickness (Figure 1). Some other design parameters arrived based on FEM simulation are: natural frequency – 2.4 MHz, Max displacement - 0.16 μm at 50 V DC + 10 V AC, stress in membrane – 256 MPa.

cMUT Fabrication

Fabrication of the micromachined capacitive ultrasonic transducer was performed using surface micromachining and wafer bonding techniques.

Surface Micromachining Method

In the surface micromachining technique, membrane was made using Low Pressure Chemical Vapor Deposition (LPCVD) polysilicon fabrication process starting with a standard wafer cleaning and by growing thermal silicon dioxide on silicon wafer for cavity formation. Phosphorus diffusion was done to make bottom electrode/plate. LPCVD was used for deposition of nitride. Nitride deposition is followed by Atmospheric Pressure Chemical Vapor Deposition (APCVD) PSG (Phosphosilicate Glass) deposition as sacrificial layer. After PSG deposition and planarization, Polysilicon was deposited as active layer on membrane. Membrane patterning was followed by phosphorus diffusion for top electrode. Once electrode was formed, sacrificial layer was removed using hydrofluoric (HF) solution. Contact window was opened and aluminum was deposited followed by metal patterning for top and bottom electrode contact. Figure 2 shows the microphotograph of the single cMUT cell. However, cMUT devices fabricated by

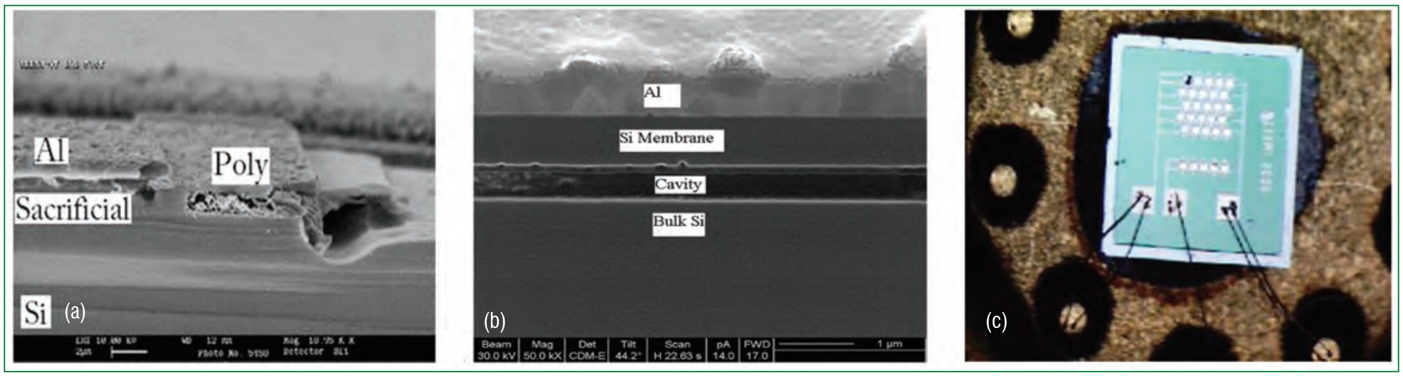


Figure 3: Cross-sectional SEM image of a single cMUT cell (a) showing the non-removal of sacrificial layer (Surface Micromachining method) (b) showing cavity properly etched out (Wafer Bonding method). However, cavity height appears to be less than the designed value (c) Diced and packaged 5×5 arrays of cMUT device

surface micromachining did not respond to any excitation. To know the cause of the device failure, a cross-sectional SEM of the devices at wafer level was carried out. From the Figure 3(a), it is seen that the sacrificial layer is not completely removed. To overcome the issues in the surface micromachined fabrication, the conventional wafer bonding fabrication technique was implemented for the next batch of cMUT device fabrication.

Wafer Bonding Method

In this fabrication technique, two wafers were used. One is single-side-polished, 4-inch, p-type, <100>, and 500–550 μm thick silicon wafer with resistivity 10–20 ohm-cm, which was used for bottom plate and the cavity formation. Second wafer was silicon on insulator (SOI) with device thickness $2.0\pm0.5\,\mu$m, handle thickness 500 ± 5 μm, and device resistivity of 2-5 ohm-cm. Standard wafer cleaning was used and thermal 1.0 μm silicon dioxide was grown on silicon wafer for cavity formation and for support (posts) of membrane. Lithography was done to pattern the cavity for each cell. Mask with different arrays of elements was used for lithography for cavity formation. Dry etching of silicon dioxide was performed to achieve 1.0 μm cavity height. Bottom silicon electrode of the cells was heavily doped by $POCl_3$ to achieve resistivity of 1-2 ohm-cm. A 1500 Å layer of LPCVD silicon nitride was deposited to act as an insulating layer.

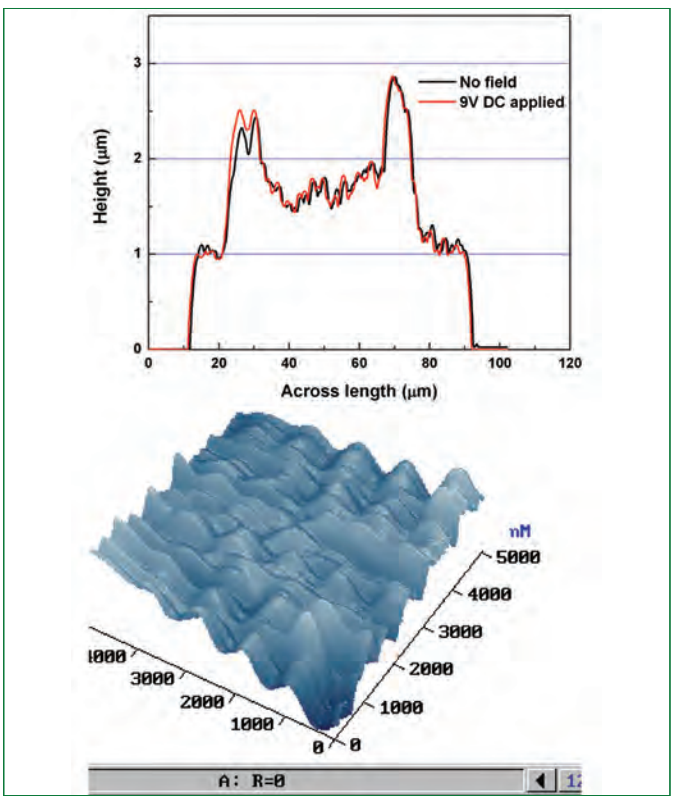


Figure 4: Surface line profile of (a) single cMUT cell with and without DC voltage and (b) surface morphology of cMUT cell.

The wafer bonding was done with a commercial wafer bonder at pressure in the range of 10^{-4}-mbar and temperature of 400°C. After this, the handle wafer from bonded silicon on insulator (SOI) was etched away (using TMAH–Tetramethylammonium hydroxide) up to the level of buried oxide layer of the silicon on insulator (SOI) wafer to form the membrane. To verify the membrane release by present method, focused ion beam milling was used to cut open a window for imaging the cross section of the device. Figure 3 (b) shows the cMUT single-cell cross-sectional view, which shows a clear cavity and confirms the successful release of the membrane. The wafer was then diced and packaged as shown in Figure 3(c).

cMUT Characterization

Surface Profile and Morphology of cMUT Membrane

Dektak Stylus Profiler was used to study the surface profile of cMUT array and membrane deformation during the application of pull-in DC voltage. Figure 4(a) shows the surface profile of a single cMUT cell. Although the expected height of membrane (1 μm) from the substrate is seen in these figures, the surface roughness of the electrode coating is large ($\approx$1 μm). This is also evident from Figure 4(b) which shows the AFM image of the Al electrode. Figure 4(a) also shows the surface life profile when a DC voltage was applied to the device. It is clear from this figure that there is no deformation taking place in the membrane due to the applied DC voltage further confirming the non-functionality of the device.

Dynamic Characterization Using Laser Doppler Vibrometer

Dynamic characterization of the device was carried out using Laser Doppler Vibrometer (LDV) at IISc. The frequency response of the device was determined and the natural frequency of the single-cell cMUT was found to be at 2.24 MHz, which is close to the design value of about 2.4 MHz.

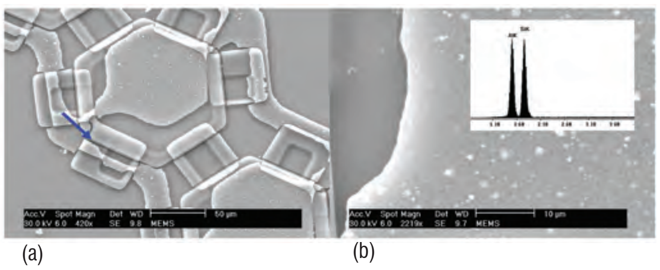
Capacitance Measurement

To study the electrical response of the device, capacitance measurements were carried out on 5×1 and 5×5 arrays using precision LCR (Inductance–L, Capacitance–C and Resistance–R) meter. Unfortunately, none of the devices were showing any constant C value and the resistance value was also low and unexpected. This clearly implies that there is an Ohmic short between top and bottom electrodes of the device. To identify this Ohmic short, further characterization was carried out using SEM.

SEM and EDS Analysis

SEM and energy-dispersive X-ray spectrometer (EDS) studies were undertaken on a cMUT using scanning electron microscopy. Figure 5 (a) and (b) shows the SEM image of one cell of 5×1 array and the interface between Al electrode and Si, respectively. Inset of Figure 5 (b) shows the EDS spectra recorded on Al and has the expected characteristic peaks of Al and Si. From these figures, one can observe that the Al electrode coating is not centered on the membrane and also it is not uniform. Also, micro cracks are seen at several places on the device (shown by blue arrow).

With the various analyses and testing described earlier of the cMUT devices with in-house characterizing tools, it has been observed that only cavity issue has been successfully addressed in the newer fabrication process. The aforementioned tests establish that the offset in Al electrode coating was the reason for



(a) (b)

Figure 5: (a) SEM image of the (a) cMUT cell and (b) Al electrode and Si interface. It is clear from these figures that top Al electrode of the fabricated device is not centered. Also several micro cracks are seen and are shown by blow arrows.

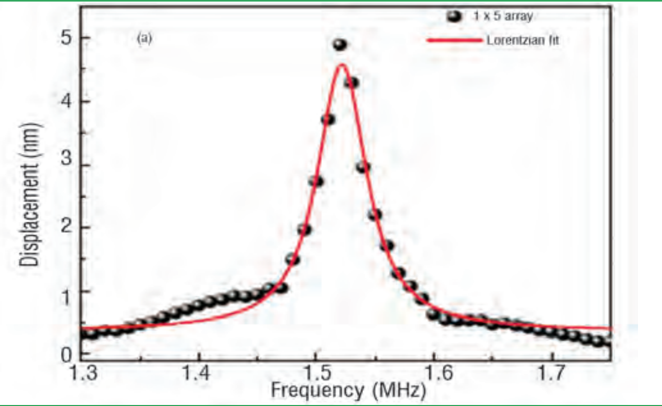


Figure 6: Frequency response of single cMUT cell measuring using NVA.

the nonfunctionality of the devices. Also, the micro crack in the top membrane permitted the Al material inside the cavity during the process of electrode coating, which causes electrical short between top membrane and bottom substrate of the cMUT device.

cMUT Fabrication with Isolation Trench using Anodic Bonding Method

To avoid these difficulties, next batch of cMUT devices were fabricated with isolation trench using anodic bonding technique. The developed fabrication process is easy, low temperature (<400°C), stiction free, reliable and gives high yield (>90%). The cMUT device is designed and fabricated successfully using the developed process, which requires silicon on insulator wafer for membrane and cavity formation and Pyrex glass wafer for cavity and bottom electrode formation. The process is used for single cell as well as for development of 1×5, 5×5, and 10×10 cMUT arrays. The resonance frequency of these devices was measured using Nano Vibration Analyzer.

A typical frequency response of a cMUT cell is shown in Figure 6. It is recorded by applying an AC excitation signal of 4V superimposed with a DC bias of 100 V. From this plot, it is clear that it has a resonant frequency at ∼1.54 MHz with a bandwidth of 48.5 kHz leading to a Q-factor of 31. Similar measurements were carried out on about 45 elements, and it is found that the resonance frequency of the measured cells is mostly centered around 1.5 MHz with a variation of ∼100 Hz. Also, the average Q-factor was about ∼28.

The design, fabrication and characterization of indigenously developed cMUT devices have been presented. Also the difficulties in fabricating these devices by surface micromachining technique and how they were overcome using wafer bonding technique are explained. Failure analysis of the device at various fabrication steps is detailed and the role of these crucial feedbacks in successful fabrication of the device is pointed out.

Reported by
Dr. J. Jayapandian and Colleagues
Materials Science Group

Young Officer's FORUM

Shri Anurag Samantara is working in Thermal Hydraulics Section of Reactor Design Group. He is from 7th batch of BARC Training school at IGCAR campus and joined the group in 2013. He did his B.Tech in Mechanical Engineering from IIT Bhubaneshwar and completed M. Tech from HBNI in 2014. His current area of work involves modeling and analysis of decay heat removal systems of future fast breeder reactor.

Thermal Hydraulics of Decay Heat Removal System for Future Fast Breeder Reactor

Decay heat is the residual heat generated in a reactor core due to radioactive decay of fission products after shutdown of the reactor. Decay Heat Removal (DHR) from the reactor core without crossing any design safety limits is very important for safety of the reactor. Various decay heat removal systems considered for conceptual design of future FBR are Secondary Sodium Decay Heat Removal System (SSDHRS), Safety Grade Decay Heat Removal System (SGDHRS) and vessel cooling system.

Safety Grade Decay Heat Removal System (SGDHRS)

Decay heat removal is carried out through SGDHRS in case of station blackout. Each loop of SGDHRS consists of three independent circulation paths, viz., primary sodium circuit, intermediate sodium circuit and air circuit. Various components of SGDHRS are; Decay Heat Exchanger (DHX), Air Heat Exchanger (AHX), intermediate sodium circuit connecting DHX to AHX and (iv) Air stack. Primary sodium on passing through the core absorbs the decay heat. The hot sodium flows through DHX while transferring heat to the sodium flowing in the intermediate circuit. The intermediate sodium transports heat from DHX to AHX, where it is transferred to the ambient air. Flow of sodium in the primary and intermediate circuits is by natural circulation. A thermal centre difference between AHX and DHX provides the required buoyancy head for natural circulation of sodium in intermediate circuit. The stack present in the air circuit generates required head for natural circulation of air. Thus, this system works completely in natural convection.

Secondary Sodium Decay Heat Removal System (SSDHRS)

Decay heat removal is carried out through SSDHRS during various planned operations, viz., fuel handling and regular maintenance etc. The SSDHRS is operated with forced circulation in sodium as well as air circuits. Circulation of sodium in intermediate circuit is carried out using electromagnetic pump. A blower is present in the circuit for force circulation of air. This is an improvement for future FBRs, compared to PFBR.

Even though the SGDHRS is provided with sufficient redundancy and diversity, there are a few common features, viz., common supporting platform (roof slab), similar heat exchangers, same coolant etc. Possibility of common cause failures (failure in these common features) limits the reliability of the system. In case of simultaneous unavailability of both SSDHRS and SGDHRS, decay heat removal is carried out using vessel cooling system. So with the vessel cooling system, the reliability of the decay heat removal system can be improved in future FBR over than that in PFBR.

Computational Modelling of Coupled Natural Circulation Loops

Generally scaled down models are chosen from economic considerations. Results from these experiments need to be extrapolated to the prototype. Towards this, process design of various scaled down models of SGDHRS has been carried out. Transient performances of the scaled down models are studied and similarities in their performance are investigated. A procedure is developed for extrapolation of results of the scaled down model to full scale prototype.

Scaling

Traditionally scaled down systems are chosen based on the power scaling. Various similitude criteria followed for process design of scaled models are, Richardson number, Nusselt number and

Euler number. The natural circulation phenomenon is simulated by maintaining the Richardson number in the intermediate circuit. Nusselt number is maintained for heat transfer from heat exchangers. Euler number is maintained in air circuit to simulate similar resistance path as that of prototype and for determination of stack height. Similitude parameters are defined as,

Richardson Number (R_i)	$\frac{g \beta H \Delta T}{V^2}$	β : volumetric expansion coefficient H : thermal centre difference between AHX and DHX ΔT : temperature difference between hot and cold sodium in intermediate circuit h : convective heat transfer coefficient D_{eq}: equivalent diameter k : thermal conductivity ΔP: pressure drop in the circuit ρ : density V : velocity
Nusselt Number	$\frac{h D_{eq}}{k}$	
Euler number	$\frac{\Delta P}{\rho V^2}$	

Four power scaled models, viz., 1:64, 1:16, 1:8 and prototype have been considered. A mathematical model is developed based on conservation principles of mass, momentum and energy. The mathematical equations are discretized using a finite difference method and are translated into a computer code for the transient analysis of various scaled down models.

Validation

The computationally predicted results are compared against the experimental data of SADHANA facility at IGCAR. Intermediate sodium flow rate is computed for various sodium pool temperatures in the range of 350-550°C and found to be in good agreement with the experiment with a maximum deviation of 1.25%.

Predicted power transfer from Air Heat Exchanger is compared with the experimental data. It is found that the power removal is under predicted by the computational model to the extent of 6%. This deviation is due to the uncertainties associated with measurement and modelling. Power transfer from Air Heat Exchanger is a derived quantity, which depends on flow rate and temperature. So deviations in the flow rate and temperature get added resulting in a larger deviation in power. Secondly, there is an uncertainty associated with the correlations used for heat transfer and pressure drop calculations.

Transient Evolution

Transient performance of various scaled models are predicted for opening of damper as transient boundary condition. Evolution of air flow rate for a damper opening time of 100 seconds is studied. The air flow rate reaches full value within a short time (~20 seconds) as soon as dampers are opened and is independent of scaling. This is due to low inertia of the air circuit.

Evolution of intermediate sodium flow rate is studied and it is found that small scale models take less time to reach full flow rate and full scale prototype takes the maximum time. This is due to large inertia in intermediate loop of higher scaled models. All the scaled models show oscillatory pattern before reaching full flow rate. This is due to combined effect of the transient disturbance and buoyancy force. It is found that the time of stabilization depends on the length of piping, cross-sectional area and flow rate of sodium. The present results are in line with this scaling.

Parametric studies were carried out to understand the effect of ambient air temperature on the capacity of SGDHRS. The variation in system capacity (%) with the change in inlet air temperature in the range of 25-60°C has been studied. It is found that capacity of the system decreases with increase in inlet air temperature and vice versa. This is due to the fall in temperature difference between sodium and air. It is observed that a 10°C increase in air temperature, reduces the capacity of the system by 4.8%.

Extrapolation Procedure

A non-dimensional study is carried out to understand the similarities in transient behavior of the various scaled down SGDHRS models. The flow rate of intermediate sodium and time are non-dimensionalized using the following substitutions,

$\tau = \frac{t\, m_{ss}}{M_{sys}}$	t : time m_{ss} : steady state flow rate of sodium in intermediate circuit
$\omega = \frac{m}{m_{ss}}$	m : flow rate of sodium at any instant M_{sys} : mass of sodium present in the intermediate circuit

It is found that the flow rate for different systems takes nearly the same non-dimensionalized time (τ=1) to get stabilized. So, if experimental results are available for small scale models then these can be extrapolated to full scale prototype to estimate the time required for establishing natural circulation in the circuit. As the heat transfer from AHX depends on the intermediate sodium flow rate, the time to reach full capacity can also be extrapolated.

Figure 1 shows the evolution of non-dimensional temperature with non-dimensional time. The temperature of intermediate sodium is non-dimensionalized using the following substitutions,

$\theta = \frac{T_h - T_c}{\Delta T_{ss}}$	T_h : hot leg temperature T_c : cold leg temperature ΔT_{ss} : steady state temperature difference between hot and cold leg

The non-dimensional temperature (θ) represents the weighted difference of temperature between hot and cold legs of intermediate circuit at any time during the transient. All the scaled down models follow oscillatory pattern before reaching their steady state values. From the Figure 1, it is evident that at τ=1.4, the non-dimensional temperatures are stabilized for all the models. This shows the similarities in the hydraulic behavior of the intermediate sodium circuits.

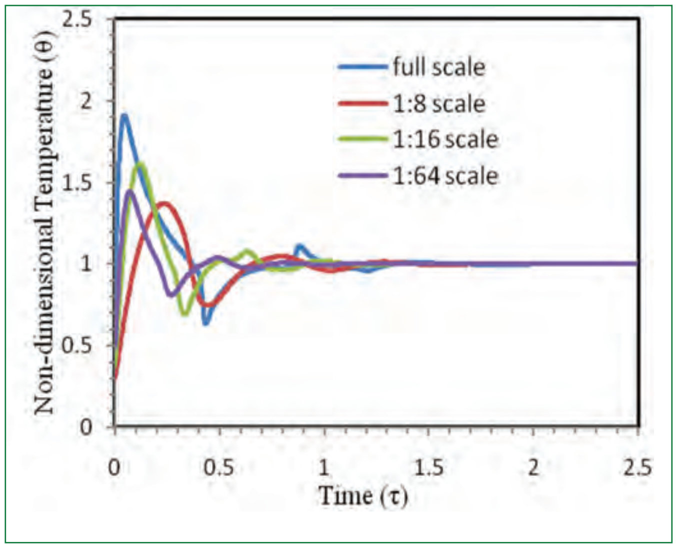


Figure 1: Evolution of non-dimensional temperature with non-dimensional time

Hood Design For Rainy Condition

To protect the Air Heat Exchanger from rain, a hood is provided on the top of the stack. Traditional hood dimension protect the Air Heat Exchanger from rain drops falling up to an inclination of 44° from vertical. But during high horizontal wind velocity, there is a possibility for rain drops being carried away by the wind and entering the stack through its exhaust window below the hood. To avoid this, various options have been studied. Computational Fluid Dynamics analysis of the hood has been carried out to study the performance of the new options.

Option 1 (Extended Roof)

In this option, the roof of the hood is extended by increasing the diameter from 7.7 meter (in reference design) to 11.4 meter. Figure 2(a) shows the modified design of the hood. Figures 2(b) and 2(c) shows the computational pressure and velocity distributions respectively in the hood region. Because of the

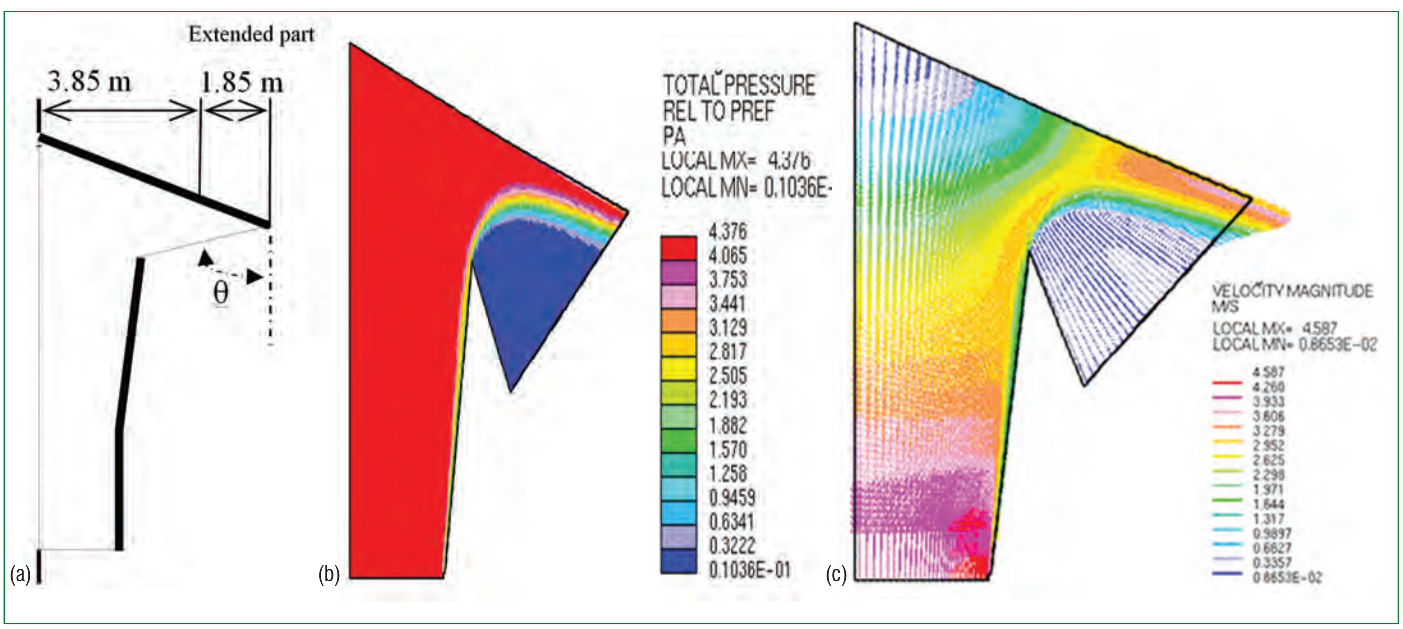


Figure 2: a) Schematic of the hood with extended roof design, b) Pressure distribution in extended roof design, c) Velocity distribution in extended roof design

extended roof, the pressure drop has increased by 0.15 Pa. This increase is found to cause negligible air flow reduction and hence the heat removal capacity. In this option, the surface area of the roof has increased by 58 m^2 (116%) with a corresponding increase in weight. This extended roof is found to avoid water drops inclined up to 78° from vertical.

Option 2 (Addition of Louver)

In order to minimize the weight of the hood, another option of inserting an additional louver at the outlet window has been studied. Figure 3(a) shows the modified design of the hood along with the louver position. Figures 3(b) and (c) show the pressure and velocity distributions respectively in the hood region. It can be seen that the air flow distribution is not significantly disturbed by the introduction of additional louver. Because of the presence of the louver, the increase in pressure drop is only 0.05 Pa (0.03%). The louver surface area is 27 m^2. Thus the increase in area is only 54% with the corresponding increase in weight, which is significantly less than option 1. This is found to prevent entry of rain drops inclined up to 70°. Addition of two louvers is found to prevent rain drops inclined up to 80° and this option is chosen for the stack.

Alternative Heat Removal Path Through Vessel Cooling System

A failure probability of magnitude 10^{-6}/ry is achieved with the present SGDHRS. Even though it is provided with sufficient redundancy and diversity, there are few common features, like common supporting platform (roof slab), similar heat exchangers, same coolant etc., which limit the reliability of the present system. In order to improve the reliability, a new option of decay heat removal is explored which works through main vessel. This system works completely on natural circulation and removes heat through a different path, there by improving the reliability of the system. Towards this, decay heat removal from the surfaces of safety vessel (SV) and guard vessel (GV) are investigated. Air, water and therminol are considered as candidate coolants. For these coolants, pressure drop in the flow path, its natural circulation capability and the heat removal capacity have been estimated. The required stack height for natural circulation of air has also been estimated.

As a part of the study, the option of introducing the guard vessel surrounding safety vessel was explored, where the guard vessel was cooled. The heat removal capacity of the guard vessel was found to be inadequate due to large heat transfer resistance for the heat to flow from main vessel to guard vessel via safety vessel. However, direct cooling of safety vessel (Figure 4) was found to be much better than guard vessel cooling. Hence this option is studied in depth.

Description

In the present study, square tubes of cross section 25x25 mm with a pitch of 100 and 200 mm have been considered for estimation of heat transfer capacity and pressure drop in the safety vessel cooling circuit. Coolant picks up heat from vessel surface while flowing from bottom to top of the vessel through the tubes in single pass and enters the outlet header placed at the top of the safety

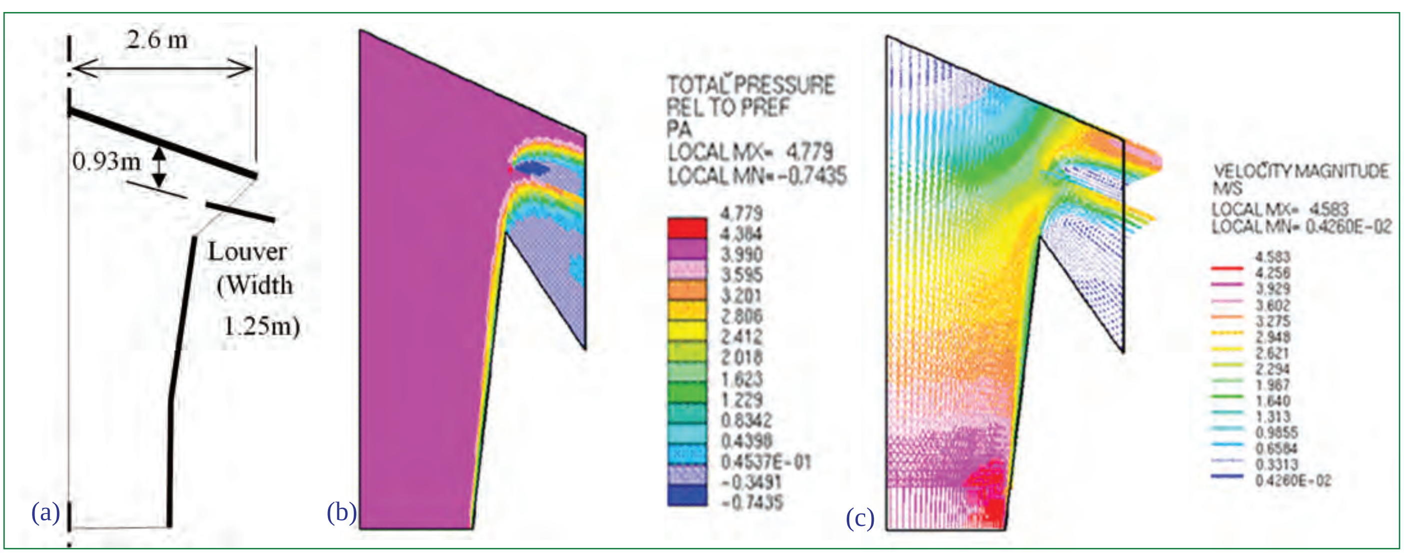


Figure 3: a) Schematic of the hood with additional louver, b) Pressure distribution due to addition of louver, c) Velocity distribution due to addition of louver

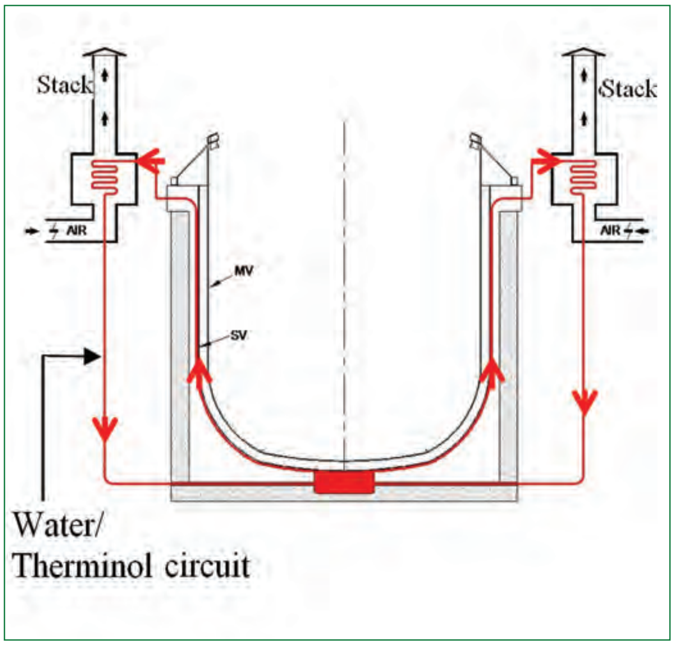


Figure 4: Schematic of safety vessel cooling arrangement for liquid coolant

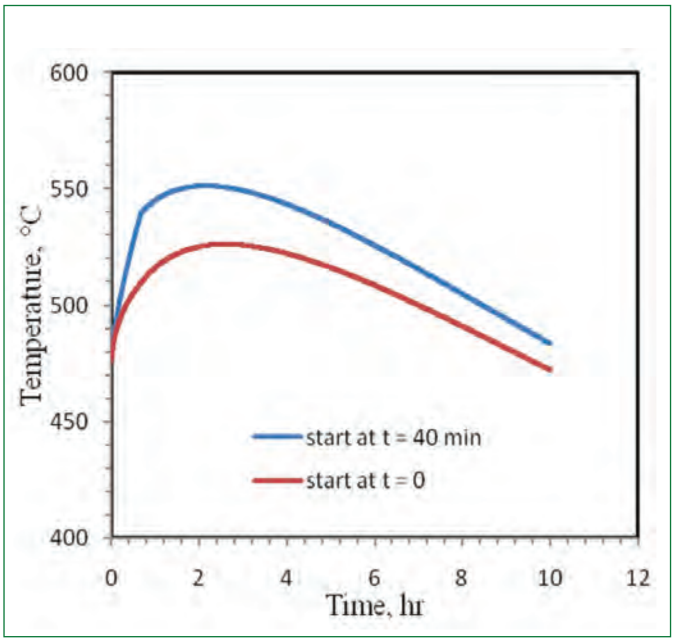


Figure 5: Evolution of sodium pool temperature with heat removal by vessel cooling system

vessel. The hot coolant from outlet header passes through a heat exchanger, where it rejects heat to the ambient air and comes back to the bottom inlet header. The flow takes place by natural circulation, where buoyancy head is provided by the height of the vessel.

Evolutions of Temperature

The main vessel-safety vessel annulus is filled with nitrogen. Hence heat transfer in this annulus is found to be controlled by thermal radiation. To respect the category-4 design safety limit of hot pool, it was found to increase the emissivity of outer surface of main vessel to 0.8 by special coating. Another option to increase heat transfer is filling the annulus with sodium during such an eventuality.

Figure 5 shows the evolution of hot pool temperature for safety vessel cooling system using therminol as coolant, where the main vessel-safety vessel gap is filled with sodium. It can be seen that a maximum temperature of 526°C is reached if the vessel cooling system is available without any initial delay. The temperature of sodium pool rises initially for some time, reaches a maximum value and then comes down. This is due to the fact that, initially the rate of heat generation is more than the rate of heat removal by vessel cooling system which increases the sodium pool temperature. The fall in sodium pool temperature is attributed to the fact that, the decay heat generation decreases with time and heat removal by vessel cooling system increases with temperature which exceeds the heat generation. If a start-up delay of 40 minutes is considered for filling the sodium, then a maximum temperature of 552°C is reached after which it comes down.

Conceptual design of Decay Heat Removal (DHR) system for future FBR has been finalised. A computational model has been developed for coupled natural convection loops of Safety Grade Decay Heat Removal system. Using this model, computational studies are carried out for various scaled down models of Safety Grade Decay Heat Removal systems. Process design of scaled down models is carried out using similitude criteria to simulate thermal hydraulics of full scale prototype. Transient performance of the scaled down models is studied and a procedure is established for extrapolation of data from scaled down experiment to full scale prototype. A Computational Fluid Dynamics study is carried out to study new designs of hood to prevent rain water entering Air Heat Exchanger in high wind conditions. A new option of decay heat removal through vessel cooling system is explored for enhancement of reliability of present decay heat removal systems. It is found that in severe accident scenario, design safety limits can be respected using vessel cooling system, if sodium is filled in inter vessel gap on demand or the emissivity of main vessel and safety vessel surface is increased to greater than 0.8.

Reported by

Anurag Samantara, Reactor Design Group

Young Researcher's FORUM

Probing of Competitive Displacement Adsorption of Casein at Oil-in-Water Interface using Equilibrium Force Distance Measurements

Shri V. Mahendran did his Masters in Applied Physics from National Institute of Technology, Trichy. He joined as a research fellow in May 2010 under the guidance of Dr. John Philip and has submitted his Ph.D thesis in May 2015 to the Homi Bhabha National Institute. The title of his thesis is "Direct Measurement of Colloidal Forces in the Presence of Different Analytes". He has published twelve papers in international journals and presented papers in five international conferences. He won the Best Ph.D. student award for the year 2014 from Institute of Smart Structures and Systems (ISSS), Indian Institute of Science, Bengaluru. Since August 2015, he is pursuing post doctoral research with Prof. Mugele at University of Twente, Netherlands.

Understanding the nature and reversibility of competitive displacement adsorption of smaller molecules at interfaces covered with macromolecules is important from practical applications point of view. Such competitive displacement adsorption provides a unique possibility to reuse adsorbents. As the competitive interactions between different adsorbing species determine the stability and product life time, several studies have been carried out on the interaction of protein-with other molecules at air-water and oil-water interface. The protein adsorption at oil-water interface is important in manufacturing industries such as, pharmaceutical, food emulsions. Milk proteins are used as a stabilizer in food hydrocolloids because of their exceptional amphiphilic nature and stabilizing properties. In bovine milk, casein consists of four major proteins, α_{s1}-casein, α_{s2}-casein, β-casein and κ-casein, which are known to adsorb rapidly at the oil-water interface and provides stability via electro-steric stabilization. α_{s1}-casein and κ-casein are the major content (~75%) of milk casein. β-casein is more hydrophobic and surface active than α_{s1} casein and resembles block copolymers with alternating charge and hydrophobicity i.e. a charged phosphopeptide loop and a hydrophobic train. The stability aspects of protein stabilized emulsions, under various conditions like temperature, pH, cations and biochemical environment, have been studied in food hydrocolloids. In general, the polymer adsorption at solid interfaces is strongly influenced by solution properties such as pH and ionic strength. We attempt to obtain better insight into these complex interactions between proteins and oil-water interface in the presence of diblock polymer mediation using insitu colloidal force measurement. Here, we probe the competitive displacement adsorption efficiency of casein at an oil-water interface stabilized with either neutral polymer by employing intermolecular force, zeta and hydrodynamic diameter measurements. The questions this study would address are (a) Are casein proteins effective in displacing adsorbed diblock copolymers from oil-water interface? (b) How casein-diblock polymer interaction affects the force parameters and stability of oil-in-water emulsions? (c) What is the effect of polymeric size on nature of forces during and after competitive displacement adsorption?

Surface force apparatus, atomic force microscopy and optical tweezers are the traditional techniques used to probe the intermolecular forces. Optical tweezers are ideal for measuring the long range interactions between micron size particles, whereas atomic force microscopy measures the interaction between a macroscopic surface and a mesoscopic surface and surface force apparatus probes the force between two mica surfaces. The above techniques do not facilitate direct measurement of colloidal force. To overcome the above limitation, we have developed a technique called magnetic chaining technique (MCT), that allows probing of intermolecular forces between the magnetic colloidal droplets. This technique is based on the diffraction of light by chains of magnetic particles under an applied magnetic field. One of the important highlights of this technique is that the force measurement is based on averaging over an extremely large number of particles. We used a stimuli-responsive oil-in-water nanoemulsion stabilized with diblock copolymer-polyvinyl alcohol-co-vinyl acetate (PVA-Vac) of two different molecular weights (40K, 115K) for our studies. PVA-Vac is an amphiphilic polymer, where the hydrophobic Vac part goes into the oil phase and the hydrophilic PVA extends into water. Due to finite size of confined segments (excluded volume effect) and hydration layers, the steric force magnitude and range can be much greater than $10R_g$, in aqueous solutions, where Rg is the unperturbed radius of gyration of the polymer.

When an external magnetic field is applied, droplets form one dimensional (1D) chain like structure due to overwhelming magnetic dipolar attraction. For infinitely long droplet chain, the dominant dipole-dipole attractive force is

$$F_{chain} = -\sum n \frac{6m^2}{(nd)^4} \text{ and } m = \frac{\mu_0 4\pi a^3 x_s H_T}{3}$$

and here 'm' is the magnetic moment of each drop, 'μ_0' is magnetic permeability of free space, 'x_s' is the magnetic susceptibility and the total magnetic field $H_T = H_{applied} + H_{induced}$. As the periodicity of 1D chain lies in the visible wavelength region, Bragg reflection is seen when the sample is illuminated with a white light. The diffraction from an 1D chain follows Bragg's law, $2nd\sin\theta = N\lambda$ where 'n' is refractive index of continuous medium (water), 'd' is the distance between the centers of adjacent droplets, 'N' is the order diffraction, 'θ' is the diffraction angle and 'λ' is the diffraction wavelength. For 180° geometry, the first order Bragg's condition is and the corresponding interdroplet spacing is given by, $h = d - 2a$ where 'a' is the droplet radius. By controlling applied magnetic field 'd' can be varied precisely.

Figure 1(a) shows the force distance profile for PVA 40K stabilized emulsion at different casein concentrations. At all the studied casein concentrations, force profiles decay exponentially with interdroplet distance.

The force profile without added casein is taken as a reference curve, which was exponentially decaying. It has been shown that the force profile between polymer covered particles is repulsive and can be represented by a simple exponential function,

$$F_r(h) = \frac{K_b T \pi R}{\lambda^2} exp[-h/\lambda]$$

where 'h' is interparticle spacing and 'λ' is decay length. From the best fit to above equation, we have extracted three parameters, λ from the slope, $2L_0$ or the first interaction length, that corresponds to the interdroplet spacing at a force magnitude of 2.8 x 10^{-13} N, and magnitude of force (K) which is dictated by the adsorbed polymer layer. Without casein, the characteristic decay length λ = 7.5 nm, which was close to the unperturbed R_g value of free polymer measured using viscometry (~ 8 nm). With the addition of 0.004 wt% of casein, the decreases from 7.5 to 7 nm. The λ values were 6, 5 and 4.5 nm for 0.016, 0.054 and 0.14 wt% casein, respectively. Interestingly the $2L_0$ decreases drastically from 77.5 (~$10R_g$) to 57 nm (~$7R_g$) when 0.14 wt% casein is present in the emulsion where the force magnitude also increases from 10 to 30 nN with casein. Figure 1b shows the force distance profile measured at varying casein concentrations for PVA-Vac 115K stabilized nanoemulsion. The force distance curves were exponentially decaying with interdroplet distance, though slight deviations are observed at the higher casein concentrations. Without casein, λ = 10.5 nm, which is close to the unperturbed R_g value of PVA 115K measured from viscometry (~12nm). The decay lengths were 9.8, 7.4, 6.7, 6 and 4.5 nm for 0.004, 0.008, 0.016, 0.029, 0.096 and 0.14 wt% of casein, respectively. In this concentration range, the onset repulsion decreases from 88 (~7.3 R_g) to 48 nm (~4 R_g), where as the magnitude of force increases from 1 to 19 nN.

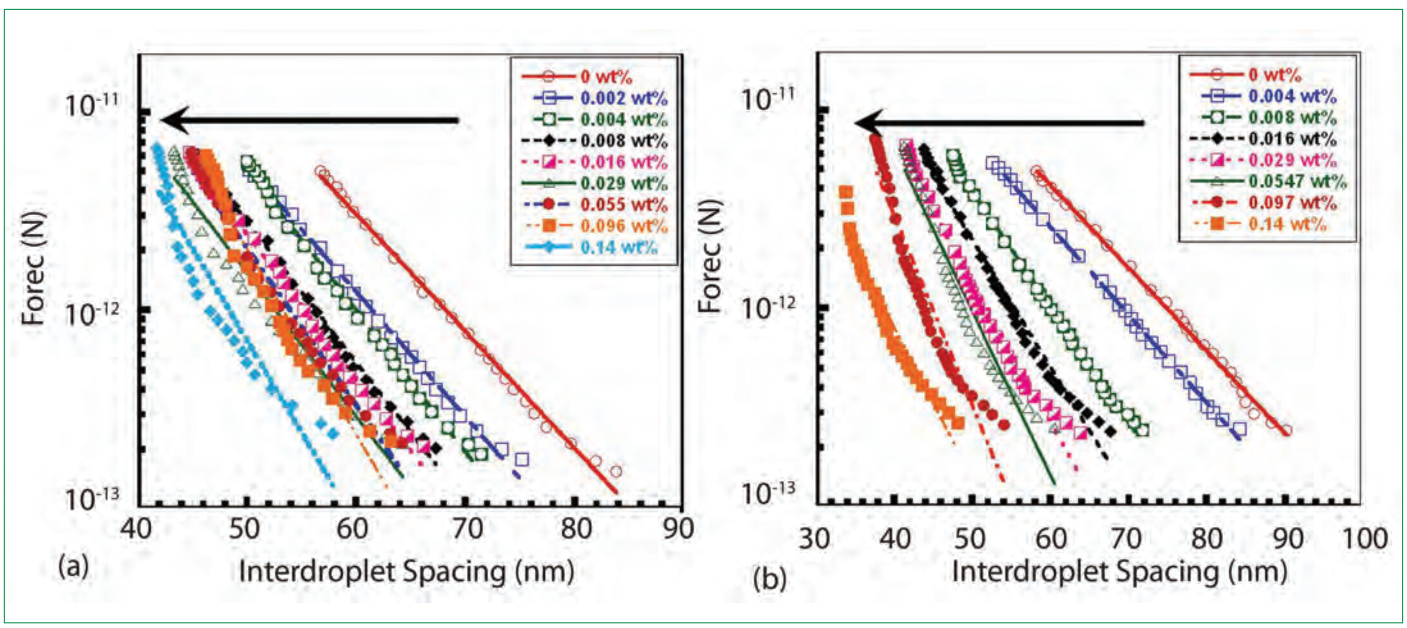


Figure 1: Force distance profiles at different casein concentrations for PVA-Vac (a) 40K and (b) 115K stabilized emulsion. Solid lines correspond to the theoretical fit.

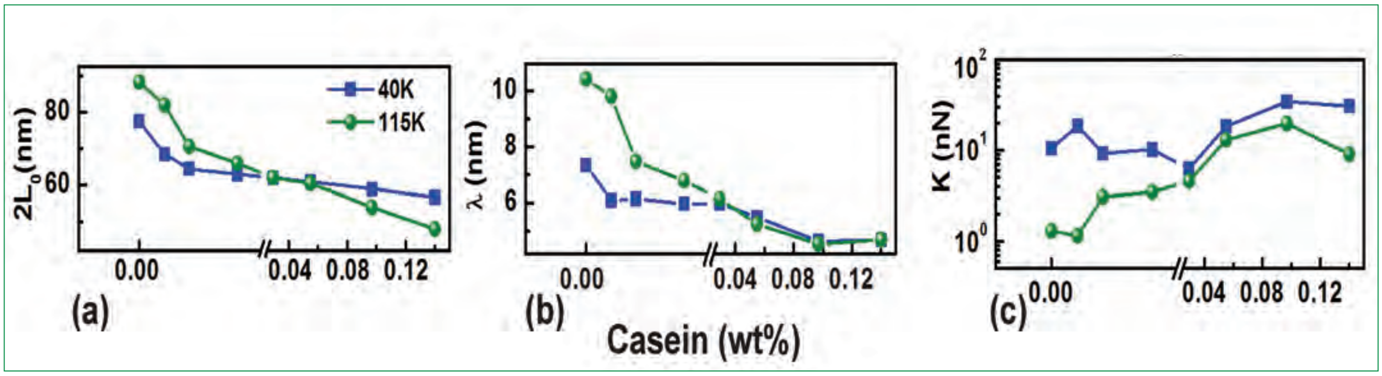


Figure 2: (a) First interaction length ($2L_0$), (b) decay length (λ) and (c) force magnitude (K) for PVA-Vac 40K(square) and PVA-Vac 115K (sphere) as a function of casein concentration.

Figure 2 shows the change in ($2L_0$), λ and K as a function of casein concentration. For both 40 and 115K stabilized emulsion λ and ($2L_0$) values decrease with casein concentration whereas an increase in the force magnitude is observed. The significant diminution in the λ and ($2L_0$) value suggests that the adsorbed polymer is replaced by casein through competitive interaction. If the polymer remains at the interface along with the casein molecules, the decay length would not have reduced to 4.5 nm. The increase in force magnitude with casein concentration suggests that the casein volume fraction at the droplet interface also increases. As expected, such adsorption of casein molecules at the interface leads to an electrostatic repulsive force due to the negative charges of α_{s1} and β casein (-22 e and -15 e, respectively). To understand the competitive displacement adsorption phenomena, we have carried out zeta potential measurements in PVA-vac 40K stabilized emulsion at different casein concentration.

Figure 3 shows the autocorrelation function, hydrodynamic diameter and zeta potential for different casein concentration for PVA40K stabilized magnetic nanoemulsion. All the measurements were carried out at 25˚C and the plotted results are the average of forty five measurements.

The average hydrodynamic diameter of the emulsion droplets with 0, 0.01, 0.02, 0.04, 0.07, 0.14 and 0.21 wt% casein are 295, 284, 280, 270, 264, 244 and 189 nm, respectively. Up to 0.04 wt% of casein, the hydrodynamic diameter distribution was narrow and monomodal but on further increase in casein concentration, the distribution became broad (100-300 nm), though the peak remains monomodal. The significant reduction in the hydrodynamic diameter (~ 120 nm less) with 0.21 wt% of casein, unambiguously confirms the competitive adsorption of casein by displacing the adsorbed polymer molecules at the oil-water interface. Obviously, such displacement of adsorbed polymers should lead to a reduction in the $2L_0$ values due to absence of extended polymer trains, loops and tails from the oil-water interface, which is in excellent agreement with our results. To confirm this further, we have carried out the zeta potential measurements with different casein concentrations

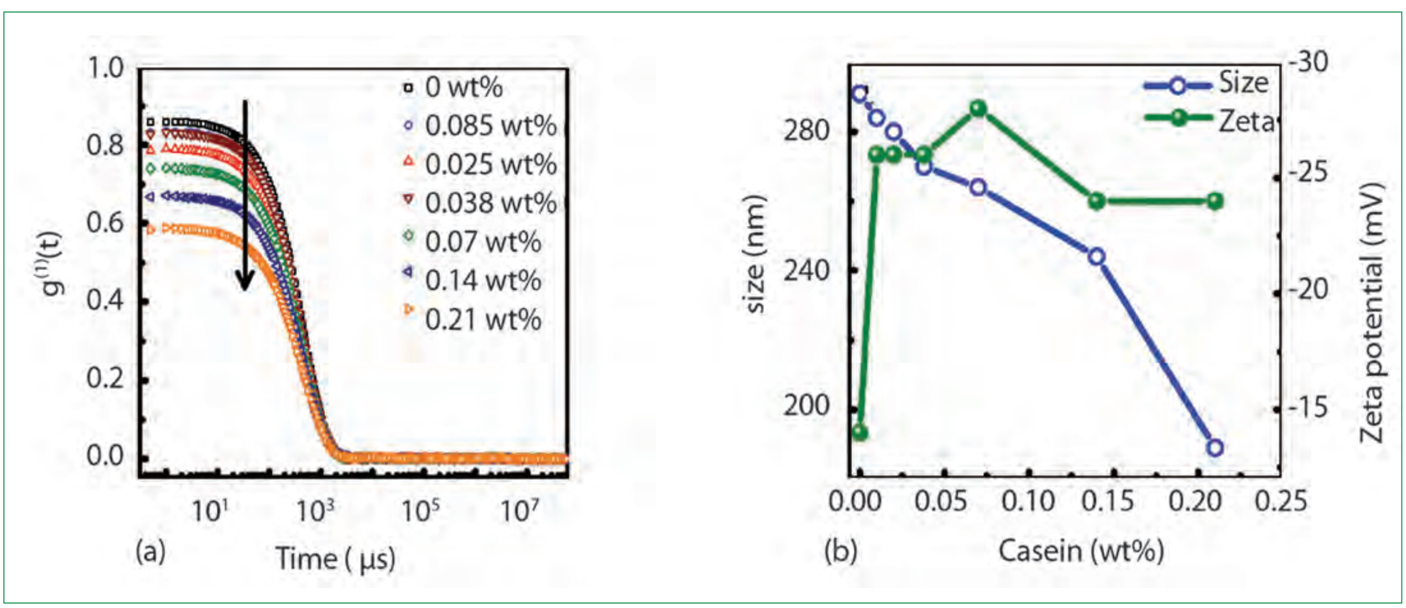


Figure 3: (a) Auto correlation function as a function of time at different casein concentrations (b) hydrodynamic diameter (open symbols) and zeta potential (solid symbols) for PVA-Vac 40K stabilized emulsion (pH6.53) as a function of casein concentration.

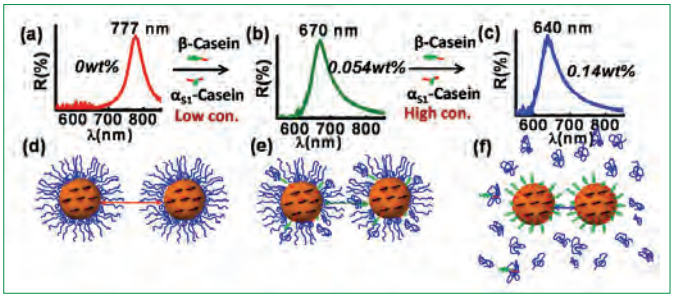


Figure 4: (a-c) Bragg peak at 0, 0.054, 0.14 wt% casein concentrations at a fixed magnetic field of 126 Gauss and (d-f) the schematic representation of β-casein and α_{s1} casein conformation at the oil-water interface.

and the results are shown in the Figure 3(b). Though the oil-in-water emulsion droplets are washed and incubated with polymers, some residual negative charges are present at interfaces due to anionic surfactant used during the emulsification process, which gives rise to the observed negative zeta potential value of ~-15 mV (pH 6.53). When casein concentration is increased to 0.01 wt%, the zeta potential value increases to - 26 mV and remains constant thereafter. Amongst the four major protein components α_{s1}-casein, α_{s2}-casein, κ-casein and β-casein, α_{s1}–casein and β-casein are the main individual components coexisting at oil-water interfaces. Our results are in good agreement with the earlier findings that both α-casein and β-casein molecules can absorb strongly and coexist at oil-water interfaces. Therefore, the adsorption of casein molecules at the oil-water interface by replacing the pre-adsorbed PVA-vac molecules is evident from the increase in the zeta potential and the decrease in hydrodynamic diameter with increasing concentrations of casein. From earlier studies, it was concluded that the adsorbed β-casein has an extended long tail in aqueous medium, whereas the α-casein forms a short loop at the interface and the interaction between β-casein adsorbed interfaces is strongly repulsive at all ionic strengths due to contributions from steric and electrostatic forces. The net repulsive interaction observed in the present study shows that the β-casein is adsorbed at the oil water interface contributes to the repulsion, as the interaction between α-casein covered interfaces is attractive.

The complete displacement of adsorbed polymer by displacer molecule is favorable, if the desorption energy of the displacer molecules is greater than or equal to the adsorption energy of the polymer segment, which was derived from the critical displacer concentration, ϕ_{cr}, at which the polymer surface excess vanishes. According to theory, the displacer adsorption energy is given by,

$$\chi_s^{pd} = \ln\phi_{cr} + \chi_{sc} - \lambda_1\chi^{pd} - (1-\phi_{cr})(1-\lambda_1)\Delta\chi^{do}$$

where, λ represents the fraction of contacts a lattice site makes with sites in one of the adjoining layers and $\Delta\chi^{do}$ is the combined solvency parameter defined as,

$$\Delta\chi^{do} = \chi^{po} - \chi^{pd} - \chi^{do}$$

where, ^{po}, ^{pd} and ^{do} correspond to the contact free energies between polymer and solvent, polymer and displacer, displacer and solvent, respectively. The adsorption of flexible polymers at interfaces is governed by the free energy of mixing of polymer and solvent, represented by Flory-Huggins parameter, the free energy associated with the formation of polymer-surface contacts and the concomitant breaking of solvent-surface contacts.

The hydrodynamic diameter and zeta potential data suggests that a very low concentration of casein (0.01-0.2 wt %) is sufficient for the complete displacement of adsorbed polymers (~0.6wt %) from the oil-water interface. The force measurement, hydrodynamic diameter and zeta results suggest that casein form a patchy coverage on SDS covered oil-water interface whereas they vividly adsorb at oil-water by displacing the larger PVA-vac polymer molecules. Based on our results, the conformation of polymer, surfactant and casein at oil-water interface along with the experimentally obtained Bragg peak positions at various concentrations of casein are schematically represented in Figure 4. With increasing concentrations of casein in the dispersion, casein molecules form a patchy coverage at oil-water interface due to the hydrophobic interactions. Figure 4 (a-c) show the diffraction peak without and with different casein concentrations in PVA-vac stabilized emulsion and Figure 4 (d-f) shows the corresponding changes in the interdroplet spacing.

With increasing concentrations of casein in the dispersion, casein displaces PVA-vac and adsorb at the oil-water interface. With addition of casein in PVA-vac diblock polymer stabilized emulsion, the onset repulsion decreases from 88 to 48 nm where as the force decay length (~10.5 nm) is reduced to 4.5 nm upon addition of casein, which provides unambiguous evidence for the replacement of extended polymer coils by smaller size casein molecules. The hydrodynamic diameter and zeta potential results, corroborate the observed casein mediated polymer displacement and adsorption of casein at oil water interface. Our results suggest that the casein molecules are effective displacers for replacement of adsorbed macromolecules from emulsion interface, which may find several important practical applications for reuse of formulations.

Reported by
Shri V. Mahendran
Metallurgy & Materials Group

Conference and Meeting Highlights

Graduation Function of the 9th Batch of Trainee Scientific Officers of BARC Training School at IGCAR

July 29, 2015

Dr. Srikumar Banerjee, Shri M. K. Narayanan, Dr. P. R. Vasudeva Rao and Dr. M. Sai Baba during the release of souvenir at the graduation function

The 9th batch of forty six Trainee Scientific Officers from the BARC Training School at IGCAR have successfully completed their training and were graduated in a special ceremony that took place on July 29, 2015. Shri M. K. Narayanan, Former National Security Advisor and Former Governor of West Bengal was the Chief Guest. Dr. Srikumar Banerjee, Homi Bhabha Chair and Former Chairman, Atomic Energy Commission presided over the function. Dr. P. R. Vasudeva Rao, the then Director, IGCAR and GSO, welcomed the gathering. Dr. Vidya Sundararajan briefed the audience about the Orientation Course in Engineering and Sciences programme. Dr. Srikumar Banerjee delivered the presidential address. Shri M. K. Narayanan released the souvenir featuring the training school programme in the previous academic year and Dr. Srikumar Banerjee received the first copy. Shri M.K. Narayanan gave away the prestigious 'Homi Bhabha Prizes' comprising of a medallion and books worth Rs.5000 to the toppers from each discipline and addressed the gathering. He also gave away the course completion certificates to all the graduates passing out. A few of the Trainee Scientific Officers passing out shared their experience, gave a feedback on the academic programme and their stay at the hostel.

Dr. M. Sai Baba, Associate Director, Resources Management Group, proposed the vote of thanks.

Reported by M. Sai Baba,
Associate Director, RMG

Graduates of BARC Training School at IGCAR with Shri M.K. Narayanan, Former National Security Advisor & Former Governor of West Bengal, Dr. Srikumar Banerjee, Homi Bhabha Chair and Former Chairman, AEC , Dr. P. R. Vasudeva Rao, the then Director, IGCAR & GSO, Dr. M. Sai Baba, AD, RMG and senior colleagues of the Centre and the Department

Conference and Meeting Highlights

BITS Practice School

May 22 - July 16, 2015

Students from BITS Practice School with Dr. S. Venugopal, Director, MMG and Dr. M. Sai Baba, Associate Director, RMG during the valedictory function

Twenty five students from BITS Pilani, Hyderabad and Goa campuses underwent Summer Practice School at our Centre during May 22-July 16, 2015. This programme is aimed at exposing the students to industrial and research environments, how the organizations work, to follow and maintain work ethics, study the core subjects and their applications in the organization, participate in the assignments given to them in the form of projects. The students were from various disciplines like Chemical Engineering, Computer Science & Engineering, Electrical & Electronics Engineering, Electronics & Instrumentation Engineering, Electronics & Communication Engineering, Mechanical Engineering and Information Systems. Dr. Parameshwaran, BITS Practice School Division was the programme coordinator. Students carried out challenging projects in various Groups of the Centre according to their discipline. During the period of their stay, they visited various facilities at IGCAR, BHAVINI and MAPS. As a part of the curriculum, quiz, project work presentations, group discussions and report writing were done. The valedictory function was held on July 16, 2015 with Dr. S. Venugopal, Director, Metallurgy and Materials Group delivering the valedictory address and distributing the certificates to the students.

Reported by M. Sai Baba,
Coordinator-BITS Practice School

Conference and Meeting Highlights

Summer Training in Physics and Chemistry (STIPAC - 2015)

26 May - 03 July, 2015

Dr. Anil Kakodkar, Former Chairman, Atomic Energy Commission and Dr. P. R. Vasudeva Rao, the then Director, IGCAR along with the students during the valedictory function

The STIPAC programme for the year 2015 (being conducted for the 17th time) coincided with the International year of Light. The theme chosen was "Lasers in Physics & Chemistry". Forty students, twenty each from 157 applicants for Physics and 130 applicants for Chemistry were selected for the STIPAC-2015 based on their academic credentials, their write up and the interest evinced to pursue scientific research. Theoretical courses were held in forenoons. The students were given a hands-on experience by either doing project work or carrying out experimental work on various topics. Towards the end of the course, the students gave a presentation on the work done and answered questions from the audience.

Apart from this, quiz programs and lectures on special research topics were also held. Problem solving sessions were conducted by Dr. S. V. M. Satyanarayana, a former scientist of IGCAR and currently an Assistant Professor in Central University, Puducherry. In addition, the students were also taken on a site visit to MAPS, BHAVINI and DAE-UGC node.

The STIPAC-2015 was inaugurated by Dr. C. S. Sundar, J C Bose Fellow & former Director, MSG. He gave a historical perspective of evolution of Light as a tool in the research on Condensed Matter. This was followed by a keynote address on Photonic Crystals & Band Gap Materials by Dr. B. V. R. Tata, Head, CMPD, MSG. Prof. S. Anantha Ramakrishna, IIT Kanpur, gave a talk on the need for and the research potential in Optical Meta Materials.

Dr. Anil Kakodkar, INAE Satish Dhawan Chair of Engineering Eminence, Former Chairman, Atomic Energy Commission & Secretary, Department of Atomic Energy and Dr. P. R. Vasudeva Rao, the then Director, IGCAR & GSO addressed the students during the valedictory function on 03 July, 2015.

Dr. Anil Kakodkar distributed the certificates to the students of STIPAC 2015.

Reported by
Course Co-ordinators of STIPAC 2015

Visit of Honourable Minister Dr. Jitendra Singh, to DAE Facilities at Kalpakkam

21 August, 2015

Dr. Jitendra Singh, Minister of State with Dr. R. K. Sinha Chairman, Atomic Energy Commision and Dr. P. R. Vasudeva Rao, the then Director, IGCAR & GSO during his visit to the Centre

Honourable Dr. Jitendra Singh, Minister of State for Development of North Eastern Region (Independent charge) and Minister of State for Prime Minister Office Personnel, Public Grievances & Pensions, Department of Atomic Energy and Department of Space, Government of India visited various Units of the Department at Kalpakkam on 21 August, 2015.

He was accompanied by Dr. R. K. Sinha, Chairman, Atomic Energy Commission, Dr. Sekhar Basu, Director, BARC and Shri K.C. Purohit, CMD, NPCIL.

Honourable Minister visited the Madras Atomic Power Station. Programme started with introductory remarks by Dr. R. K. Sinha and Dr. P. R. Vasudeva Rao, the then Director, IGCAR and GSO delivering a presentation. He visited exhibits of Fuel bundle for Thermal Reactors, Control Room and Fuel Handling facility at the Madras Atomic Power Station.

During his visit to our Centre, he has seen the Fast Breeder Test Reactor, exhibits of Fuel Sub-assemblies for Fast Breeder Test Reactor and Prototype Fast Breeder Reactor, the Reactor Containment Building and an exhibition of models and charts covering all the important activities of the Centre.

Honourable Minister, also visited Protoype Fast Breeder Reactor at BHAVINI. Before concluding the visit, addressed senior DAE Scientists and Engineers across all Units, wherein Dr. P. Chellapandi, CMD, BHAVINI, welcomed the gathering, Dr. R. K. Sinha, Chairman, Atomic Energy Commission gave the introductory note and Dr. P. R. Vasudeva Rao delivered the vote of thanks.

Conference and Meeting Highlights

Quality Circle Annual Meet (QCAM) - 2015
September 08, 2015

Dr.P.R.Vasudeva Rao, the then Director, IGCAR & GSO and G.Srinivasan, Director, ROMG & RDG along with the participants during the valedictory function

Quality circle is a small group of employees doing similar or related work who meet regularly to identify, analyze, and solve work related problems usually led by a senior team member. After completing their analysis, they present their solutions to management for implementation and to improve the performance of the organization. Thus, implemented correctly, quality circles can help the organization to reduce costs, increase productivity, and improve employee morale.

In IGCAR, every year Quality Circle Annual Meet (QCAM) is conducted and the QC case studies are presented by the QC teams. QCAM–2015 was conducted on 08 September, 2015 at Convention Centre and SRI Seminar Hall, Anupuram in parallel sessions. Welcome address was delivered by Shri A. Jyothish Kumar, Director, ESG, the Presidential address by Shri G. Srinivasan, Director ROMG & RDG. Inaugural address was delivered by Dr. T. Paul Robert, Professor, Department of Industrial Engineering, Anna University, Chennai and vote of thanks by Shri G. Kempulraj, Head, Central Workshop Division.

Twenty Five Quality Circles and delegates (about 300 members) from IGCAR, schools from Kalpakkam and neighborhood presented QC case studies in a wide spectrum of topics covering Technical, Research & Development, Services and Education. Professional judges from Quality Circle Forum of India, Chennai chapter, adjudged the QC case study presentations. Under the 'Mechanical and Manufacturing' stream, the PLUTONIUM QC Team bagged 'Dr. Placid Rodriguez memorial trophy', while EXCEL QC team bagged the 'Shri M. K. Ramamurthy memorial trophy' for Plant Operation and Services category. EINSTEIN QC form AECS-2, SIGMA VIER MAGNA QC from KV-2 and KURUMBU QC, Government HSS,Vengampakkam have won the "Dr. Sarvepalli Radhakrishnan memorial trophies" in the School category.

During valedictory function, the events were summed up by Shri. K. G. Subramanian, Convenor, QCAM-2015. The programme was concluded with the valedictory address and the prizes were distributed to the participants by Dr. P. R. Vasudeva Rao, the then Director, IGCAR & GSO and Shri G. Srinivasan, Director, ROMG & RDG. Vote of thanks was proposed by Shri T. V. Maran, EIC, ZWS, Member Secretary, Organising committee.

Reported by G. Kempulraj,
Member Secretary,
Apex Steering Committee on Quality Circles, IGCAR
QCAM 2015

Diamond Jubilee Celebrations of the Department of Atomic Energy at Kalpakkam

Towards commemorating the six decades of our Department a series of lectures, exhibitions, visits to facilities at IGCAR for students from various colleges and educational institutions and outreach programmes were organized. Some of the programmes organised as part of the celebration during the months, July - August, 2015 are highlighted below:

"Know your DAE" Lecture series:

During this period, Dr. R. Chidambaram, Principal Scientific Advisor, Government of India delivered a talk on the topic "India's Nuclear Programme: the Main Thrust and the Spin-Offs" on July 24, 2015 during his visit to the Centre. Dr. Anil Kakodkar, INAE Satish Dhawan Chair of Engineering Eminence, Former Chairman, Atomic Energy Commission and Secretary, Department of Atomic Energy delivered DAE Diamond Jubilee Colloquium on "Harnessing Technology for Development : A Governance Challenge in Indian Context" on July 03, 2015.

Outreach & Awareness Programmes:

Several exhibitions were organized across Tamil Nadu. Exhibits were displyed at Anu Vigyan Exhibition conducted at Subbiah Vidyalayam Girls Higher Secondary School, Tuticorin organised by HWB, Tuticorin on 05 July, 2015 and at nearby villages at Kalpakkam by Sahodari Mayam, Tamil Nadu Science Forum, Anupuram in coordination with IGCAR during 10-11 July, 2015. Posters depicting various activities of IGCAR along with sodium sample were isplayed at NESCO CARNIVAL during 31 July to 09 August 2015. These exhibitions played a major role in educating the public about nuclear energy and the activities of DAE. It also helped in dispelling the fear about the activities of the Department to the visitors.

State Level Inter Collegiate Quiz Competition -2015

As part of the DAE Diamond Jubilee Celebrations, IGCAR organized a State level Inter-Collegiate Quiz competition for the science students of undergraduate (UG) and postgraduate (PG) level separately.

For each zone, a college was identified to serve as the zonal co-ordinator and the quiz competition was held in this college. The topics covered in quiz are: History of radiation and radioactivity, basic nuclear physics, nuclear chemistry, nuclear reactors and locations of nuclear installations in India and uses of ionizing radiation in the fields of medicine, industries, food irradiation etc.

Preliminary screening in each zone was done by a written test and the top twelve teams were selected at UG and PG level respectively from the list of teams registered for the quiz event. There were three students in each team. Semifinal quiz was conducted in parallel session for the two groups and top three teams from each group were selected for final round of quiz. Top three teams were selected in final round of quiz and awarded with trophy and certificates. The winners and runners of each zone a total of 18 UG teams and 18 PG teams participated in the Grand finale held at Chennai.

The grand finale of this quiz competition for all the six zones was conducted at Stella Maris College, Chennai on 23 July, 2015. The zonal winners were invited to Kalpakkam on 24 July, 2015. Totally 36 teams participated in the event. Transportation was arranged from Kalpakkam to Stella Maris College, Chennai for the participants. Similar to the zonal finals, Twelve teams each from UG and PG level were made into two groups and semifinal was conducted in parallel sessions. The first, second and third places was bagged by Malankara Catholic College, Kaliakkavilai from Zone 1, Ayya Nadar Janaki Ammal College, Sivakasi from Zone 4 and Loyola college, Chennai from Zone 2 respectively at the PG level and Stella Maris College, Chennai from Zone 2, Sri Vasavi College, Erode from zone 5 and Kamban College for women, Tiruvannamalai at the undergraduate level. Overall, a total of 1215 students from more than 100 colleges participated in this event.

In conjunction with the quiz, an exhibition highlighting the Indian Nuclear Energy program, beneficial applications of ionizing radiations and demonstration of radiation detection and measurement equipments was also organized. The exhibition with posters and models was a grand attraction. More than 1500 students from schools and colleges attended and benefited from this science exhibition. The major focus of the programme was to create a general awareness on nuclear science and technology, its benefits, varied applications in society and research and career prospects.

The Prize Distribution ceremony was held on 24 July, 2015 at Homi Bhabha Building, IGCAR, Kalpakkam. Dr. R. Chidambaran, Principal Scientific Advisor, Prime Minister's Office, New Delhi distributed the memento and certificates to all the winners. The finalists from all zones had the opportunity to visit the Fast Breeder Test Reactor and the various other laboratories at IGCAR. The program organized under the guidance of Dr. P. R. Vasudeva Rao, the then Director, IGCAR & GSO and coordinated by Dr. M. Sai Baba, Associate Director, RMG, Dr. B. Venkatraman, Associate Director, RSEG, Shri S. Chandrasekaran, RSD, Smt Jalaja Madan Mohan, RMG and colleagues from EIRSG, RMG and other groups was a grand success.

Indian Nuclear Society (Kalpakkam) had prepared a monthly calendar depicting the beneficial applications of ionizing radiations, pioneering role of BARC, the activities of IGCAR and other major DAE units and the career and research prospects in DAE. The calendars were distributed to all colleges in each zone for the benefit of students and college teachers to provide the glimpses of DAE activities in societal applications of ionizing radiation in addition to nuclear energy programme.

Details of colleges participated and winners from each zone

Districts / Dates	Name of College / Co-ordinator	No of teams	Details of prize winners	
			PG	UG
Tirunelveli,Kanyakumari and Tuticorin 23-24 March, 2015	Women Christian College, Nagercoil Dr.Shanthi Dickson Assistant Professor, Department of Physics	78	Malankara Catholic College, Kaliakkavilai, Nagercoil (I prize) and Nesamany Memorial Christian College (II prize)	Sri Paramakalyani College, Alwarkurichi (I prize) and Pioneer Kumaramasamy College, Nagercoil (II prize)
Erode ,Salem, Tirupur, Karur and Namakkal 15- 16 May, 2015	Kongu Arts and Science College, Erode Dr. A. K. Vidhya, Head, Department of Biotechnology	54	J.K.K. Nataraja Arts and Science College, Erode (I Prize) and Erode Arts & Science College, Erode (II Prize)	Kongu Arts and Science College, Erode (I Prize) and Sri Vasavi College, Erode (II Prize)
Tiruvannamalai, Cudalore, Vellore and Thriupathur 24-25 June, 2015	Arunai Engineering college, Tiruvannamalai Dr. R. Ravishankar, Assistant Professor, Department of Physics	71	Shanmuga Industries Arts Govt. Arts & Science College, Tiruvannamalai. (I & II Prize)	Kamban Women's College, Tiruvannamalai (I Prize) and Arcot Sri Mahalakshmi Women's College, Vellore (II Prize)
Devakottai,Pramakudi, Madurai,Virudunagar, Sivagangai and Ramnad 29-30 June, 2015	Sree Sevugan Annamalai College, Devakottai Dr. Chandramohan, Principal	50	Ayya Nadar Janaki Ammal College, Sivakasi (I Prize) and Devanga Arts College, Arrupukottai (II Prize)	American College, Madurai (I Prize) and Ayya Nadar Janaki Ammal College, Sivakasi (II Prize)
Tiruchy,Tanjavur, Karur, Pudukottai 14-15 July, 2015	National College, Tiruchy Dr. V.T. Ravichandran, Assistant Professor, Department of Physics	80	St. Joseph College, Trichy (I Prize) and AVVM Sri Pushpam College, Poondi(II Prize)	Bishop Heber College, Trichy (I & II Prize)
Chennai, Kanchipuram and Thiruvallur 22 July, 2015	Stella Maris college, Chennai Dr. Mary George, Assistant Professor, Department of Chemistry	72	Loyola College, Chennai (I Prize) and Madras Christian College, Chennai (II Prize)	Stella Maris College, Chennai (I & II Prize)

Visit of Dignitaries

Dr. Anil Kakodkar, former Chairman, Atomic Energy Commission during the colloquium

Dr. Anil Kakodkar, INAE Satish Dhawan Chair of Engineering Eminence, and Former Chairman, Atomic Energy Commission and Secretary, Department of Atomic Energy, delivered DAE Diamond Jubilee Colloquium on "Harnessing Technology for Development: A Governance Challenge in Indian Context" on July 03, 2015. During his visit, he visited Fast Reactor Fuel Cycle Facility

Dr. Baldev Raj, Director, National Institute of Advanced Studies, Bengaluru and former Director, IGCAR delivering the IGC colloquium

Dr. Baldev Raj, Director, National Institute of Advanced Studies, Bengaluru and former Director, IGCAR delivered the IGC Colloquium on "Pathways to Energy Sustainability for India" on July 09, 2015

Prof Riccardo Fenici, MD, Director of Clinical Physiology, Centre for Biomagnetism Catholic University during the IGC colloquium

Prof. Riccardo Fenici, MD, Director of Clinical Physiology, Centre for Biomagnetism Catholic University, Rome, Italy and European Director, Society for Police and Criminal Psychology visited our Centre during 20-24 July,2015. During his visit he delivered IGC Colloquium on "Cardiac Health: Probing by Non-Invasive Methods" on July 23, 2015

Visit of Dignitaries

Dr. R. Chidambaram, Principal Scientific Advisor, Government of India delivering the Diamond Jubilee colloquium

Dr. R. Chidambaram, Principal Scientific Advisor, Government of India visited our Centre and delivered a talk on "India's Nuclear Programme : The Main Thrust & the Spin-Offs" on July 24, 2015 as part of DAE Diamond Jubilee Colloquium. He visited Metal Fuel Development Laboratory at Chemistry Group and 100 Tonne Shake Table Facility during his visit.

Dr. C. Ganguly, INSA Senior Scientist & INAE Distinguished Visiting Professor, delivering the IGC colloquium

Dr. C. Ganguly, INSA Senior Scientist & INAE Distinguished Visiting Professor Hony. Adviser, Engineering Staff College of India (ESCI) and former Chief Executive, NFC visited the Centre on August 11, 2015 and delivered IGC Colloquium on "Expanding Nuclear Power Programme in India, the Prospects & Challenges and the Role of FBRs".

Prof. M.O. Garg, Director General, Council of Scientific & Industrial Research delivering Acharya P. C. Ray Memorial Lecture

Prof. M.O. Garg, Director General, Council of Scientific & Industrial Research (CSIR), New Delhi delivered Acharya P.C. Ray Memorial Lecture on "Nano Catalysis- Doing the Impossible" during his visit to our Centre on August 26, 2015.

Awards & Honours

On the occasion of HBNI completing 10 years of excellence, a function was organised at BARC Mumbai, where the awards have been given to faculty and students. Following are the details of the awards from the Centre:

Distinguished Faculty Award

Dr. B.V.R. Tata

Dr. John Phillip

Dr. K.Velusamy

Dr. U. Kamachi Mudali

Outstanding Doctoral Student Award

Physical Sciences

Dr. Prasana K. Sahoo for the thesis titled "Quasi One Dimensional GaN Nanostructures: Growth Kinetics, Physical Properties, and Applications"

Chemical Sciences

Dr. Shima P. Damodaran for the thesis titled "Synthesis, Characterization, Thermal and Rheological Studies in Nanofluids"

Engineering Sciences

Dr. S. Ravi for the thesis titled "Design and Development of In-Sodium Creep Testing Facility and Influence of Dynamic Sodium on Creep Properties of Structural Materials for Fast Reactors"

Outstanding M.Tech. Student Award

Shri Aritra Sarkar for the thesis titled "Deformation Behaviour under Ratcheting of a Type 316LN Stainless Steel"

Shri V. Arjun for the thesis titled "Finite Element Model Based Optimization of Pulsed Eddy Current Probe for Sub-Surface NDE"

Dr. Sandip Dhara has been conferred membership in the American Chemical Society and also he has been elected as member of The Royal Society of Chemistry

Dr. John Philip has been conferred membership in the American Chemical Society

Best Paper Awards

Bioinspired Superhydrophobic Surface by Deposition of Fluorinated Si nano Particles on Type 304L stainless Steel
Ms. M. Ezhil Vizhi, Ms. S. C. Vanithakumari, Dr. R.P. George, Ms. S. Vasantha and Dr. U. Kamachi Mudali
International Corrosion Symposium for Research Scholars (CORSYM 2015) at IIT, Madras, 31 July – 01 August, 2015

Common Tern

Published by Scientific Information Resource Division, IGCAR, Kalpakkam-603102