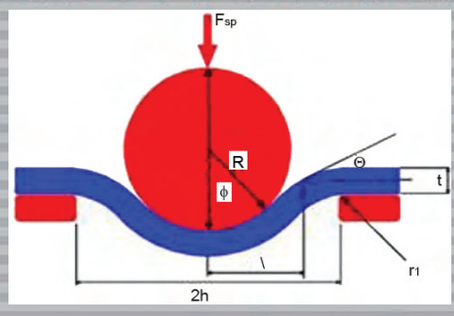
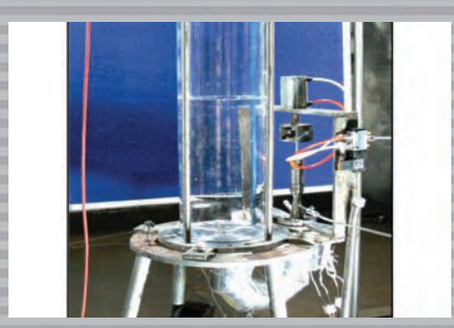
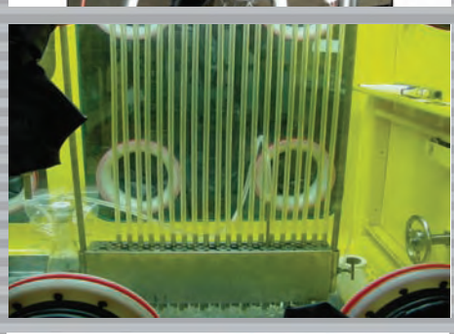
ISSN 0972-5741 Volume 99 January 2014

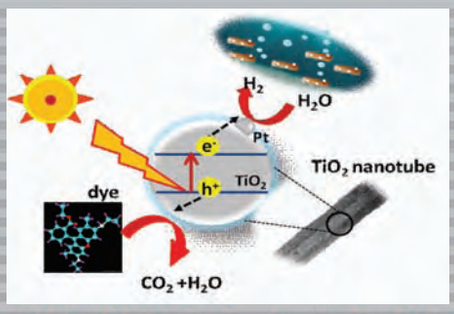
IGC Newsletter

IN THIS ISSUE









INDIRA GANDHI CENTRE FOR ATOMIC RESEARCH
http://www.igcar.gov.in/lis/nl99/igc99.pdf

From the Editor

Dear Reader

It is my pleasure to wish you a very happy and pleasant New Year 2014.

It is my pleasant privilege to forward a copy of the latest issue of IGC Newsletter (Volume 99, January 2014, issue).

In this issue we have had the great feature of Dr. G. Venkataraman, Director (Retd.) ANURAG, DRDO & Former Vice- Chancellor, Sri Sathya Sai Institute of Higher Learning, sharing his experiences with a team of young officers.

In the first technical article Dr. M. D. Mathew and colleagues have evolved an innovative testing technique to evaluate the creep properties of materials in relatively shorter durations for optimising the chemical composition in order to develop creep resistant steels.

In the second technical article Dr. P. Chellapandi and colleagues have highlighted the studies on mitigation of sodium fire through nitrogen injection and carbon microsphere application.

In the Young Officer's forum, Shri A S Suneesh has reported the development of a new method based on bis(2-ethylhexyl)diglycolamic acid (HDEHDGA) as extractant and diethylenetriamine pentaacetic acid (DTPA) as aqueous complexing agent towards separating lanthanides from actinides.

In the Young Researcher's forum, Dr. Rajini P Antony has shared her experience in fabricating one dimensional TiO_2 nano-architectures by electrochemical anodization and their energy and environmental applications.

This Newsletter carries reports on the "Theme meeting on Stainless Steel for Power Sector" and 9th Biennial National Conference on Recent Advances in Information Technology (READIT)".

Dr. G. Venkataraman, Director (Retd.) ANURAG, DRDO & Former Vice Chancellor, Sri Sathya Sai Institute of Higher Learning, Prof. K. Ramnarayan, Vice Chancellor, Manipal University and Bharat Ratna Prof. C. N. R. Rao, F.R.S., National Research Professor, Honorary President & Linus Pauling Research Professor, Jawaharlal Nehru Centre for Advanced Scientific Research visited the Centre during the last quarter.

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

New Year Message

Dear Readers,

I wish you and your families good health, contentment, prosperity and bliss during the New Year 2014.

The year 2013 has seen all round progress in our activities. All the Groups in the Centre have made significant and excellent contributions towards different aspects of the fast reactor programme, including physics, chemistry, materials, instrumentation, safety, etc. Fast Breeder Test Reactor, the flagship of our Centre, acquired license to operate until June 2018. FBTR has served as an excellent test facility for various materials including fuels. The introduction of sodium bonded, enriched uranium-zirconium metal fuel pins for test irradiation marks an important step in the development of metal alloy fuels for future fast breeder reactors. The fabrication of sodium bonded test fuel pins with U-19Pu-6Zr alloy slugs has also been completed and the fuel pins will be shortly introduced in FBTR. A capsule containing annular pellets of mixed oxide fuel and two sphere-pac test fuel pins is also currently under irradiation. All these irradiation experiments would provide vital inputs for the fast reactor programme.

Our Centre has broadly met its commitments to the PFBR project. All the major equipments for PFBR have been delivered to BHAVINI, barring a few equipments whose testing is in progress. During this year, the control plug and two primary sodium pumps were delivered to BHAVINI after resolving several technological challenges. The Under Sodium Ultrasonic Scanner has been qualified and is ready for shifting to BHAVINI. The full scope training simulator has been commissioned at BHAVINI. The criticality of PFBR, expected during the coming year will mark an important milestone in our country's fast reactor programme. With our commitment to PFBR design and construction nearing completion, our focus will now be on the two FBRs to follow. The conceptual design of FBR-1&2 along with detailed design of reactor assembly has been completed through structural mechanics and thermal hydraulics investigations. Our major effort now is to optimise manufacturing sequence and technologies for the permanent components of the reactor assembly towards reducing the cost and time of the construction.

CORAL has continued to perform satisfactorily with improved performance. Significant progress has also been made towards completion of construction activities in Demonstration Fast Reactor Fuel Reprocessing Plant and it is possible to start cold commissioning with uranium in the coming year. Our most important challenge in the coming years will be the construction and commissioning of the Fast Reactor Fuel Cycle Facility, which would be essential for early closure of the fuel cycle of PFBR. With the receipt of construction clearance as well as the financial approval for the Fast Reactor Fuel Cycle Facility, the construction work at site is ready to start. Our strategy to take advance actions on many of the major packages, we believe, will help us to meet the challenging schedules. I look forward to the active support of all the groups in the centre to this project.

Metal fuelled FBRs will be the mainstay of the country's fast reactor programme in the coming decades. The conceptual design of 500 MWe Metallic Demonstration Fast Reactor has been completed. Recognising the fact that the fuel cycle for metal fuelled reactors would pose many challenges, we have taken early initiatives towards development of various elements of the fuel cycle, including fuel fabrication. With respect to pyroprocessing, experiments with the engineering scale Ambient Temperature Electro Refiner Facility have provided important inputs to the design of the electrorefiner. The commissioning of the High Temperature Electro Refiner facility during the coming year will provide additional, key inputs that would be vital for initiating the conceptual design of the pyro-fuel cycle facility for processing test fuel pins that would be discharged from FBTR. I believe that the pyroprocessing development is an important area where we need to intensify our efforts and involve several groups across the centre as well as collaborate with outside research groups, to expedite the developmental work.

Several generic R&D areas related to FBRs are being addressed by different groups in the Centre. The development of newer clad materials as well as structural materials for fast reactors as well as reprocessing and waste management programmes is a typical example, where we have continued to make sustained progress. During the year, nitrogen enhanced 316LN stainless steel with improved mechanical properties has been developed. In the domain of safety, our efforts have been to understand the sodium concrete interaction and molten uranium-sodium interaction, adjacent tube wastage phenomenon in steam generator, sodium aerosol dispersion in open environment, etc, qualify the leak collection trays at a system level, and obtain accreditation of the Biodosimetry Laboratory by AERB till 2016.

While progressing on the mission programmes of the department, we have also continued to provide valuable support to various other national mission programmes. We can be proud of the fact that the pyro-devices used in the MANGALYAAN mission of ISRO, were examined by neutron radiography using the KAMINI reactor. We have completed several qualification tests in 10 ton capacity shake table for BHAVINI and NPCIL, especially on large size rupture discs and VAT valves. The 100 ton shake table that is under commissioning would be the first of its kind in the country, and would provide several important data for optimizing the design of future reactors through better understanding of structural dynamics. Our contributions to other important National programmes include the development of Indian reduced activation ferritic martensitic steel with optimized mechanical properties and the associated fabrication methodologies for the Indian test blanket modules for testing in ITER, in collaboration with IPR, MIDHANI, ARCI, DMRL and DRDL; development of welding procedures for 304HCu SS and alloy 617M boiler tubes produced indigenously as part of the national programme on development of advanced ultrasupercritical technology. In addition, several programmes of societal interest have continued, such as experiments on production of P-32 isotope through irradiation of strontium sulphate in FBTR, development of MCG using SQUID sensors and development of infrared thermography as a screening tool for breast cancer.

Our national and international collaborations have formed an important ingredient for the success of our programmes, and we need to take steps to strengthen these collaborations.

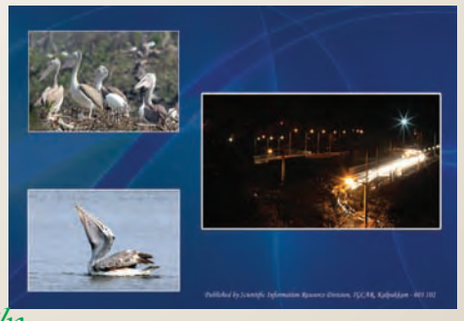
The peer review of the physics, chemistry and metallurgy programmes organized during the year have given valuable inputs towards fine tuning our R&D efforts in these domains and for planning our future programmes. In the coming year, we would cover other domains such as sodium technology and component testing, as well as safety.

As a constituent institution under HBNI, our Centre has had a healthy record, and the contributions by the research scholars have added much value to our progress. The BARC Training School at Kalpakkam has moved to a new venue this year, and we will continue to look forward to the human resource inputs from the training school for steering our current and future programmes.

It is heartening that the year that passed has been rewarding to the Centre in all fronts. I look forward to your unstinted support, cooperation and dedicated efforts to scale further challenges in the coming year. I once again wish you all a very happy and prosperous new year and wish that the New Year would usher in more successes to you, your families and the organization.

(P. R. Vasudeva Rao)

Director, IGCAR



Wish you and your family bliss, health and successes during the year 2014

Interaction with Dr. G. Venkataraman

Dr. G. Venkataraman interacting with the team of young officers and Dr. M. Sai Baba, AD, RMG

Sir, you are one of the founding fathers of IGCAR, formerly known as the Reactor Research Centre.We would like to hear from you your early experiences.

First of all, I would like to tell you that I am NOT the founding father of IGCAR; rather, I was only an early settler. I would give the tag Founding Father to Vikram Sarabhai, whose vision led to the creation of IGCAR -there cannot be any question about it. He had great visions for this Centre and I do hope they all come true.

Sir, looking back was there any incident that shaped your career?

I have a long way to look back and when I do all that occurs to me is that I was lucky, luckier than I perhaps deserve. I am grateful to God for giving me all the various opportunities I have had to be useful to others.

I cannot remember any particular incident that shaped me, but one accident did happen to me which in some way helped me to come to science. After college I joined, as my father wanted me to, the Indian Institute of Science; the idea was to study electrical engineering. One day while studying in the Institute, I got down from a bus I was riding. After getting down I tried to cross the street walking behind the bus which is clearly a wrong thing to do. A cyclist coming from the opposite direction hit me and I fell down; in the process my hand got fractured.

This happened in January 1955. For the next three months, I did not attend classes in the afternoons because it was either drawing or workshop, for both of which one needed two hands. Since one of my hands was in a plaster cast, I got exemption on the condition that I would do all that later. Now I.I.Sc. had a very good mess, and every day I ate a big lunch and slept in the afternoon. In the process, I gained 20 pounds which was not at all nice! Meanwhile, my father realized that my heart was not in engineering but in physics. One day he sent me an advertisement for TIFR for Reasearch Assistants and asked me to apply. I applied but didn't really want to go to TIFR, because I felt that people in Mumbai dressed fashionably and that I would be a misfit amongst those people. At that time I had only two shirts and thought I would look like a villager; so while I sent in the application, I really did not want to go to TIFR. My father was in Mumbai and insisted that I come and attend the interview.

Prof. Bernard Peters was the Chairman of the Interview Committee that examined me, and Prof. A. S. Rao was one of the committee members. It so happened that when my name was called, I was in the rest room. So the next person in the list was called in. Later when I showed up, I was called in; in fact, I was the last fellow to be interviewed and they asked me a lot of questions. I was very casual, answering whatever little I knew; considering the replies I gave, I was sure I would not be selected.

Prof. V. Balakrishnan of IIT, who at one time was here in IGCAR (and known to us as Bala) was living next door to us in Mumbai – he was a school

Dr. Ganesan Venkataraman did his Ph.D. (1966) from Bombay University specializing in condensed matter physics. He served as the Director, Physics, Electronics and Instrumentation Group, Indira Gandhi Centre for Atomic Research, Kalpakkam; Director, ANURAG, Defence Research and Development Organization; Distinguished Scientist, DRDO. Dr. Venkataraman has carried out studies in neutron scattering, lattice dynamics, mechanical properties of matter, non-crystalline state, neutral networks and image processing.

Dr. Venkataraman worked for technology transfer to computer industry and advanced VLSI design and fabrication. He served on the editorial board of Pramana. Dr. Venkataraman is recipient of the Sir CV Raman Award (UGC) (1979), Jawaharlal Nehru Fellowship (1984-86), Padma Shri (1991) and Indira Gandhi Prize for Popularization of Science of INSA (1994). He is a Fellow, Indian Academy of Sciences and Materials Research Society of India.

boy then. It turns out that his father and my father were colleagues in the Meteorological Department and they were both living in the same building. Now it so happened that the brother of Bala's father, was working in Banaras and Prof. A. S. Rao of TIFR had earlier worked in BHU. He moved over to TIFR to help Bhabha in his cosmic rays experiments – Prof. Rao was an electronics man. Bala's father said to my father, "I know Prof. A. S. Rao. I will take your son to his house and we will find out if your son has been selected." So we went to A.S. Rao's apartment in Mahim and Bala's father asked him whether I had been selected. Mr. Rao replied,"Yes this boy has been selected." He then said to me, "You go and meet Dr. Ramanna." I then met Dr. Ramanna in the Old Yacht Club (OYC) and he said, "Start working from tomorrow."

I reported for work the next day and thought I would be paid from the day I started work. There were three of us who joined Dr. Ramanna at that time, and all three of us would go to the lady at the desk in OYC and inform her that we had reported for work that day, and that she should make a note of it. Three months later on September 05, 1955, we all got the appointment order. The date on the order meant that we would be paid from September only! The Government of India thus took work out of us for 3 months but did not pay!

Years later Prof. Peters left TIFR and went to Denmark. A few years after that he came for a brief visit and at that time, Dr. Rammana told me to take Prof. Peters around the Cirus reactor. I did so and finally said to Prof. Peters, "Professor, can I ask you a question? You were the Chairman of my Interview Committee. After seeing me here today, do you feel that you made a mistake?" Prof. Peters just grinned and did not give a straight answer! Frankly, I really did not expect to be selected. God was kind to me. In the early years I often thought I was not doing well and would be sacked. Back then, I didn't know that Government cannot easily fire people!

Life was simple back then. I remember one day Dr. Ramanna asked me to shift a drum of heavy water from OYC to Trombay to do some experiments at the Apsara Reactor. The experiments related to slowing down and the thermalisation of neutrons in heavy water. I went to Lions Gate – the docks were there and that is where one found trucks. I hired a truck, took it to OYC and loaded the drum of heavy water. Someone, I think it was some administrator, asked me what I would do if there was a leak. I replied, "I have some rubber tubes, cans to collect the leakage," and so on and took the drum to Trombay. Today, I cannot imagine what I did. A drum of heavy water costs a fortune and being a strategic material cannot be handled in that casual fashion!

I can recall a similar experience connected with a small experiment we did in the early days at Apsara Reactor. This experiment had to be done round the clock. In the experiment, neutrons were scattered of a substance and the change in energy on scattering had to be assessed. This had to be done in a crude way back then, and we basically followed a method used earlier by Peter Egelstaff of England. Basically, we allowed neutrons from the reactor to be scattered from a sample and then looked at the scattered neutrons at a particular angle. We then counted the number in the scattered beam directly and after allowing the scattered neutrons to pass through a gold foil and counted that number also. If I remember right, we had gold foils of different thickness and did the counting. The experiment basically boiled down to comparing the gold transmission for the direct neutron beam with that for the scattered beam. The change in the gold transmission allowed us to say something about energy exchange between the incident neutron and the scattering material. The data had to be collected round the clock and printed out as the counting sequence was going on. When we came in the morning, there would be a long strip of paper with all the data printed out, which we then analysed. The gold used in the experiment had to be 99.99% pure, and we got it from Reserve bank. We wrapped up the gold in thin aluminium foil using tapes and used it for the experiment. Nobody knew that within the aluminium foil was gold. We collected a lot of data, and eventually published the results. After the experiment was over, that gold came to me and I put it in my drawer. It remained there, nearly half a kilo of pure gold! When I left BARC in 1973 to move to Kalpakkam, I gave all that gold to P.K. Iyengar and said, "I am handing over this to you. Do whatever you want and I have no receipt for this."People were very honest in those days.

Can you please share with us the excitement and enthusiasm that you experienced while starting this Centre?

The question is short but the answer has to be long. One day in the early seventies, late Dr. P. K. Iyengar identified few of us who had spent 10-15 years at BARC and conveyed to us that a new centre would be coming up at Kalpakkam. He wanted a few of us to go there. The persons he addressed were all hard boiled. Who would like to leave a place like Mumbai and come to an out of the way place like this? You must remember that back then Kalpakkam was way out in the wilderness. The people Iyengar talked to just listened, even as he tried to sell this place very hard; but nobody was ready to buy it! Somehow, I said I would go and I also tried to rope in two or three people but they all stayed back. Many privately told me that I was committing scientific harakiri. Looking back, in a sense it was so. Back then, I had fairly a high level of accomplishment in the subject, and also a reasonable international reputation in a new field. With everything going for me, moving to Kalpakkam was like walking away from a fortune. I cannot forget the fact that my wife had to make a huge personal sacrifice. She was working in TIFR and had to resign her job to join me; there was no way in which she could be absorbed here.

I landed at Kalpakkam, early December in the year of 1973. It was not exactly a very exhilarating experience. But in the years that followed we brought in a lot of people, most of whom were from Training School. We had very little by way of facilities but slowly we built them all up. Looking back I feel it was far better coming here rather than staying back in BARC. I say so because when Dr. Sundar recently sent me the brochure that was prepared for a visiting peer committee, I was really astonished by the amount of work that has been done in recent years in the area of Materials Science, Condensed Matter Physics, Accelerators, etc. Frankly, I never imagined we would come this far. I feel that if I was associated with giving a

kick start to a lab which has since enabled many to do good work and advance their careers, I should be quite happy. In many ways, this is superior to working for my own self advancement.

This sort of thing happened to me once again when I left this place in 1987 to go to Hyderabad to start a new lab. One difference this time was I took Dr. Neelakantan from here. I told him,"When I came to Kalpakkam there was nobody to receive me; so you go to Hyderabad one day earlier and receive me when I come!"Over there, for several weeks we both were in the same room at the Guest House of DRDO, wondering how we should get going. We got a DRDO car allotted to us and went to the bazaar to buy simple tools like hammer, spanner, screw drivers, etc. In other words, we had to literally start from a scratch. For me it was the third time! That lab named ANURAG has come quite a long way and is about to complete 25 years. If I were to compare ANURAG and this place, I would say this Centre has done much better than ANURAG. In my time, I have visited many labs, and I can honestly say that the work done at IGCAR is as good as the work done in any European or American lab. Indeed you need a lot many such labs to give muscle to the country's scientific programme. My only regret is the work being carried out here is not receiving the attention and credit it deserves. You stand in the merit of what you have done and it is really excellent.

Sir, what in your experience is most fulfilling, performing research or establishing labs?

You see when there is something positive happening and you are associated with that, it is really fulfilling. Research is only one way of finding fulfilment. If I have motivated a lot of young people to do something with their lives and find happiness that too is equally fulfilling. Right now I am working with many young people. Of course the work we are doing is not associated with science. It is quite different and all about taking the message of goodness to the public via media tools such as radio, essays, plays, videos, documentaries, etc. That work also gives me joy. When you see a smile on the other person and make that person happy, that gives me immense joy and this has been the tradition of our nation too. At my age I should be relaxing reading newspapers and books, but shortly I am hoping to be associated with 50 rural schools, motivating, encouraging and attempting to impart passion to the really deserving students to come up in life with flying colours. I look forward to this experience.

When you started MSL, what was your vision was it reactor oriented materials research or basic research?

There used to be a famous saying amongst Chicago gangsters: "If you can't lick 'em join 'em'". When I came here I was the only physicist, while the rest were hard-core engineers. So what does one physicist do in the midst of a huge bunch of hard-core engineers? Having taken the step and come here, I could not go back. So I had to try and prove myself useful. I then went about smuggling physics in the name of being useful to the reactor people - that was the strategy I adopted. I said we will do materials science. People here were talking about radiation damage, etc. Now you see it is physicists who know about radiation, and it is physicists who had built up knowledge of the interaction of radiation with matter. I thus argued that physicists had a legitimate role to play here; and I was confident that we indeed had a role to play. Today I was very happy when Dr. Sundar showed me experiments being done here where in a charged particle is bombarded on a material while at the same time helium ion is injected to simulate helium production in neutron irradiated material. That is what you call a real good experimental backup as compared to mere talk about radiation damage. When I declared that we would be involved in radiation damage studies, it was a sort of gamble. I am happy to see that over a period of time that approach has led to a lot of valuable scientific knowledge. The nice thing is that Dr. Sundar and his colleagues have been able to do regular condensed matter science along with applied studies like on radiation damage. On both fronts there has been no compromise in either quality or rigour. In other words, by making a solid contribution in the area of radiation damage, physicists here also earned the right to pursue knowledge for its own sake. This is very important for an organization, because otherwise pure scientists would become merely contractors. You should not become a contractor. When you do basic science your mind wanders here and there and you get a lot of ideas which is a good thing for creativity. That said, creative ideas must also find application. The most important thing is that our early work created legitimacy for the pursuit of knowledge for its own sake in a Centre, which, to start with, was not interested in publishing papers, research, and so on. I am so glad to see how much that culture has since changed. I still remember how in the early days people used to ridicule our staff saying, "You are all trying to show off by working even on holidays."Those days are gone now you have got affiliation with Universities, and so many scholars are visiting you for their doctoral programmes; this is really a revolution. After nearly 40 years you have been able to maintain the freshness. That is something of which you must be proud of. At the same time, you must guard against decay. One thing I saw here in this trip is that people are intensely involved in whatever it is they are doing. In TIFR and BARC both of which I have visited in recent times, there were people who were working but not getting recognition. There were also people who were slacking. On the whole the scene was rather patchy and people appear to have become increasingly selfish and self-centred. Over here, I see a lot more of team work which is a good sign.

What kind of changes you see with respect to the development of Township?

I cannot answer that question honestly, because I came to Township last night and was put up in the Guest House. This morning I was telling Shri Chakravarthi that we have to walk around the township and see how things are. So far, I have not been able to do that.

How challenging was it for you to settle at Kalpakkam coming from a hub of a city and one of India's premier lab?

If you have a bad marriage, what you do is you live with it! I was just joking. Actually there was the thrill of recruiting young people. We got a lot of bright people, like Prof. Balakrishnan who had completed his Ph.D. from America. We also had Dr. Sushanta Dutta Gupta, who got the Young Scientist Award while working here, and so on. We actually stumbled on soft matter physics and the enthusiasm we created made us forget our

handicap. Altogether, we managed to get off to a good start. I am really amazed to see the work done by Dr. Radhakrishnan, Dr. Bharathi and Shri M. P. Janawadkar. Dr. Radhakrishnan said to me,"Sir, we will check your heart and brain in our machine (squid-based MCG)." I ducked by telling him,"I have neither a heart nor a brain!"

I did not take the challenges of the early days as a hardship. Rather, like the early settlers who went to America, I took coming here as an opportunity. Of course it was tough going and we had to fight hard battles for promotions and allotment of quarters and so on.

What were your experience when you moved to ANURAG from IGCAR, in other words how was your transition from condensed matter physicist to heading a DRDO Lab involved in high end VLSI design?

First of all, I must make it absolutely clear that I personally did not do any VLSI design. All I did was to establish ANURAG, where VLSI design was one of the many activities that was pursued. In that sense, I only helped people to do VLSI design. The way it all happened was as follows:

I was a Nehru Fellow from 1984 to 1986. It gave me leave of absence from DAE but I worked as a JN Fellow mostly from Kalpakkam. When my Fellowship was over, I 're-entered' DAE but was rudderless for about two years, for reasons we need not go into now. Prior to this, even though I was on leave from the DAE, I was, for nearly two years, actively connected with the Indore Centre now known as the Raja Ramanna Centre for Advanced Technology. I did this on the explicit suggestion and request of Dr. P. K. Iyengar and thus it was that I became deeply involved in planning the Indus -I and Indus -II Synchrotrons. In fact it was I who named them.

Sometime in late 1985 or so on the initiative of Prof. C. N. R. Rao, INSA awarded three of us a Fellowship to go to USSR to work at a synchrotron radiation Centre there. Our destination was Academgorovo or Science City, near a big city known as Novosibirsk in Siberia. This city is on the Trans-Siberian railway and is three hours by air from Moscow. In fact, on the map, Novosibirsk is on the same longitude as Kanpur. The three people who were to go to Science City were, apart from myself, Ajay Sood who is now in I.I.Sc and Dr. V. C. Sahni of BARC who later became Director RRCAT and helped to complete the synchrotron projects I started way back. Dr. Ajay Sood and I went from here while Dr. Sahni joined us in Delhi. We went to Novosibirsk via Moscow.

The way this Science City came up is interesting. During World War II when the Germans attacked Russia, Stalin moved all the labs to Siberia where the scientists set up a city called "Science City". Today, this city is full of labs like laser laboratory, molecular laboratory, and so on. We were in the Institute of Nuclear Physics set up by a famous Russian Scientist named Boris Kidrich. While there, we were supposed to do some experiments using the synchrotron radiation source there. I was in Russia for only fifteen days after which I came back, while Ajay and Sahni spent three months in all. I will now tell you why I brought in this story.

On our way to Moscow, we had to stop at Delhi. I had a day off and I took the opportunity to meet Dr. Arunachalam, who, by the way, is from the second batch of BARC Training school. At that time Arunachalam was the Scientific Advisor to Raksha Mantri; he succeeded Dr. Rammanna to the post. Dr. Arunachalam asked me what I was doing those days and I replied that I was on my way to Moscow. He then suggested that on my return I join his Departmentand become involved with the development of parallel computers. He insisted that India badly needed supercomputers, for designing the Light Combat Aircraft (LCA). This aircraft was supposed to fly 1.4 times faster than the speed of sound, and a project to design and build the LCA prototype had already been assigned to the Aeronautical Development Agency (ADA) in Bangalore. Dr. Arunachalam said to me, "Why don't you come out of whatever it is you are doing now and help the DRDO in the development of parallel computers?" I told him that I did not even know how many "I's" are there in the word parallel but that I would definitely think about his suggestion after returning from the USSR.

After returning from the USSR, I met Dr. Neelakantan, who at that time was here in the EIL. Neel and I had worked together on many things and he being an original thinker, it was natural I turned to him. Later, Neel went on to become the Director of ANURAG. Prior to this, the Americans had given a CRAY supercomputer to the Indian Meteorological Department as an one-time exception. This Cray machine had a single processor that was like a huge engine but it had to be cooled to a very low temperature. The Americans had placed a fellow there at the CRAY facility to monitor the kind of programs being run on their supercomputer. They had complete veto power about what programs could be run and what could not be. That was the sort of control on technology we had to bear. Dr. Arunachalam told me that there was an alternate solution to super computers, a "poor man's solution" in fact. The idea was to stack up a large number of small-scale processors and make them do the heavy computational job by working in parallel and sharing the load. For this, the necessary condition is that the problem being tackled must be parallelizable.

Now it turns out that a large number of problems in science are indeed parallelizable, especially anything connected with atmospherics such as weather, aerodynamics, computational fluid dynamics, and so on. When a plane flies, it flies in the atmosphere. The atmosphere acts like a soft wall through which the plane has to fly. In other words, the atmosphere exerts a drag-force on the aircraft, and air-frame design boils down to coming up with an ideal aerodynamic shape so that drag forces is minimal and eddies which can cause instability are eliminated. As you can imagine, the design problem becomes particularly tough when the plane has to fly faster than sound. The computational fluid dynamics problem associated with airframe design are exceedingly complex, and the solutions can be provided only by high-end computing machineries. And such machines had to be supercomputers. What Dr. Arunachalam was asking me to do was to organise a program to build a supercomputer for the LCA project using the parallel-computer concept.

Dr. Neelakantan and I talked about the feasibility of doing this project for many days, and Neel finally said that we could do it. We then made a presentation to DRDO and our proposal was accepted. It was a real challenge, because we started with nothing literally. Over a period of time we developed and delivered a 32-node system to ADA (which, by the way, was quietly launched by Prime Minister Narasimha Rao). Subsequently, we delivered two 108-node systems, one to ADA and one to IISc, Aeronautical Engineering department. From then on, ANURAG has never looked back.

I went to ANURAG some time back, and now they have assembled three fairly big supercomputers, which are networked by a secure line devised by Dr. Neelakantan called DRONA. This trio works 24 x 7 for DRDO. Unfortunately, parallel computing is an area that is badly neglected in India, which is a huge tragedy. Although we have the brains to do the job, we seem to lack the will to get engaged in such work. That is because today's culture is all about quick returns. In science, as in all meaningful areas of human endeavour, it is hard work that ultimately delivers real success.

Another thing we promised to do when ANURAG was established was to develop chip-design capability. The entire world of microelectronics runs on chips that range from the simple to the very complex. When we started ANURAG, we had hardly any serious chip design capability in the country. When I told Arunachalam that ANURAG must be permitted to do chip design, he was quite sceptical but said yes just to get me on board. Today, ANURAG has developed atleast 50 chips since its inception, quarter of a century back. Incidentally, these days a lot of chip design is done in Bangalore for MNC's. That said, what we really lack is the ability to build chips in India. Here again, we are caught in a tight technology squeeze plus a lot of brain washing – people tell us India must concentrate on SW and we silently obey!

There is a kind of irony about all this. On one side, the country can build giant systems like nuclear reactors, missiles, etc., all of which we can legitimately be proud of. That said, somehow, we have allowed ourselves to be shut out off from the fabrication of microelectronics. Coming to chips, we still buy them and where chips for the strategic sector are concerned, you bet we are denied those. Thus in many areas, our security stands seriously compromised. By comparison, China has quietly managed to stay well ahead by proper planning. We should have organized ourselves and in fact had four decades to do so. Way back around 1964 or so, Dr. Bhabha was on the verge of launching us in this direction (after atomic energy and space) but destiny took him away. Thereafter, there was nobody in the country with his stature to tell us what we should do to further the cause. Subsequently, Americans told us, "You leave hardware to China as they are very at it; you better concentrate on software." That is how there was an e- partition! All the software India has written is related to the commercial world. True it has earned a lot of money and also created many jobs. On the other hand, there is very little of advanced scientific software. In fact, most of our scientists have forgotten how to write big codes. This is a massive tragedy because in earlier time, our scientists wrote many original programs, some of them world class. Today our scientists have become lazy. They don't write lengthy codes; instead they go to America to borrow codes and use them. This is massive and tragic mistake. Today's big science depends heavily on big and complex codes and a country which wants to ride piggy back on others codes cannot aspire to rise to high levels. You must be in a position to write big codes; only then can you be in the big league. Otherwise, you would be in the pseudo big-league. Astrophysics, particle physics, cosmology, molecular biology, and now, digital biology – all these depend on big codes because computer simulation has now become the third arm of science, joining the two earlier branches, namely, experimental and theoretical. In fact, computer modelling and simulation has now become widespread, having penetrated not only engineering but also medicine,economics, sociology, marketing, video games, movie restoration – the list is endless! Besides all this, there is now a thing called "big data" where people try to see patterns in large amount of data.

I will give you a small example of what I mean by looking at patterns. If you take any establishment like malls, there are many number of security cameras. At the time of the London tube bombing, the fellows got into the trains via the tube stations, exploded the bombs and later died. Nobody knew in which station the fellows got in. The investigating agency had to painstakingly go through all the recordings at various stations. However, with the help of parallel computers, and some AI, backed up with some descriptions about the suspects, machines can save a lot of time and labour. Indeed, if any case has to be made for big data, just look at what Edward Snowdon has disclosed! Big data does not necessarily mean spying. During oil prospecting, one accumulates massive data. Sifting that is a massive task and computers can simplify that enormously.

For a minute, let me now turn to the movie industry. The classic movie "Gone with the Wind" released just before World War II, was restored in Prasad Labs in Chennai. Being ananalog film, the entire film was first scanned frame by frame and converted into huge digital data file. As you know, one second of a movie produces about 20 frames; so you can imagine how many frames there would be in a movie lasting about 2.5 hours. In Prasad Labs, there were 100 fellows, each with his or her own computer, and this army of people did the movie restoration, one frame at a time. Each of them removed the scratches with the available software, did the colour correction, enhanced the sharpness, and so on. In India, the costs are much lower than the cost in America since human labour is involved. But suppose the Americans write a program to what 100 fellows in Chennai do; the Chennai fellows would then lose their jobs! On the other hand, the code writer can sell his code to so many customers, all of whom want to restore old films!

There are similar opportunities waiting to be taken in the entire field of 3-D animation, which is very labour intensive. Today's super computers with some AI thrown in can create a factory that churns out animation films by the hour! Speaking personally, I am not for too much technology. That said, where national policy is concerned, one has to worry about not losing jobs and so on. And in this tech age, creating the basic tools to stay ahead is what national labs like IGCAR should be at the forefront of. If elders keep national interests and make enlightened policies, the young

would be there to do the heavy lift. This is the way change must be sustained through the generations.

I have always tried to see how I could help young people who are excited to do something meaningful. This has kept me young. I can work harder than most of my colleagues and they pretty well know that! Working with young people has also helped me a lot, because active contact with a new generation allows me to learn how they think. If I have to appeal to them, I have to do many things their way; I cannot sell my old masala. It all boils down to the art of reinventing yourself constantly!

Sir you were talking about computer simulation for aircraft, what is your opinion on computer simulation in condensed matter for material design?

There cannot be any doubt about the great need for simulation work in the area of tailored materials. Elsewhere, this is an active area; I don't believe it is so in this country. Particularly in the area of nano-materials, there is enormous scope for such work. I do not know what exactly is holding us up. May be there are some problems. If you can solve those problems, you really can go far ahead.

Of course, the choice of the problem to be tackled must be made intelligently. It must be a problem that cannot be tackled easily by other methods that is, lab methods based on trial and error – that is the first requirement. If you can solve the problem by computer simulation, then you would have got a great start. Next, you have to find if somebody is really interested in this. The field of computer simulation is so vast that everybody can choose some problem or the other. The smart thing is to choose a problem that is likely to be of great interest, and do simulation work in that area.

Actually, the subject of molecular dynamics came into existence precisely in that manner. We had Dr. Singhwi and Prof. Anisur Rahman from Atomic Energy, both of whom were working on Neutron Scattering from various materials, including water. Dr. Singhwi tried to use theory to interpret the neutron scattering data, to find out how water molecules move and in general how atoms move in liquids. Prof. Rahman got fed up with the theoretical approach, since it did not seem to be going anywhere. So he decided to do something different. He played a computer game, if you can call it that. He put 864 balls of argon atoms in box and allowed them to move as they would move in a gas or liquid. Using the force law between argon atoms, Rahman followed the life history of 864 argon atoms over an extended period of time in very small time steps. This gave him tons of data that looked like a massive log book. Rahman then tried to understand this in terms of diffusion of a single particle, time-dependent pair-correlation function and so on. He got very good results. At the same time Dr. Dasannacharya and Dr. K.R. Rao were doing experiments on neutron scattering from liquid argon in Chalk River in Canada. Their results were in accord with Rahman's simulation data, but computer simulation gave much better results. As computers became more and more powerful, the sample size could be increased. Now in Livermore, the computer size is so vast that they are able to see grain boundary motion. If you are able to study things at that level and build a model for the mechanical behaviour of a solid, then you can do a lot of things, including of interest to engineering; in particular, you could design special materials – that is what tailored materials are all about. As you know, yielding, melting, etc., are all due to grain boundary movement; in short, in these areas, there is so much materials science that is waiting to be done! Metallurgists are very much interested in these areas but they are not familiar with the tools of physics. On the other hand, physicists say,"Why should I be wasting time on problems of metallurgy? I have better things to do." This is sheer snobbery. In Livermore, people are taking such work seriously but solely in the context of long-term integrity of nuclear weapons. They do such work because they are paid to do that. However, such work can easily be taken into realm of Materials Science and transformed into good Physics. I believe there is a lot of possibility in that direction.

Can you compare the research ecosystem of various national labs like DRDO, DAE and ISRO? What do you think is the basic difference?

Historically, the DAE which was born out of TIFR started off with a high research culture. DRDO came from the wrong end, that is to say, initially DRDO labs were established to give a berth for brigadiers who didn't have brigades to command! I know this because Dr. Ramanna himself told me this! Poor Dr. S. Bhagavantamand before that Dr. D. S. Kothari tried to get some research done but nothing came out of it because the top brass were hardly interested. It was Dr. Ramanna who brought about a major change during the period he was on exile from the DAE and served as SA to RM. He changed the entire set up.

In the early years after Independence, the famous Physicist & Nobel prize winner Blackett who was a close friend of Pandit Jawaharlal Nehru, told the latter that defence requirements of India are very conventional and did need any research; they could be bought off the shelf from the U.K or any other country. It was Dr. Ramanna who stressed that we must have our own defence research, at least in some critical areas. Thus he went to Madras and told the DRDO lab in Avadi to design a tank. Dr. Ramanna also clashed with Prof. Dhawan of ISRO and brought Dr. Kalam from ISRO over to DRDO. Dr. Kalam brought with him all the ISRO people he was associated with, and that was how the DRDO missile programme was born. The programme has grown with time. The culture of applied research came rather late into DRDO. Dr. Ramanna was not satisfied with what he had done. He told me, "Why don't you tell your academician friends to go and talk to the DRDO scientists and help them to solve problems using scientific rather than empirical methods, which is what they often tend to use?" Taking the advice of Dr. Ramanna seriously, I tried hard to persuade pure physicists to help out their fellow scientists in the applied filed. But our purists were too brahminical and they politely declined saying they were too busy.

In ISRO, most of the people came from Physical Research Laboratory founded by Sarabhai in Ahmadabad. Moreover, Prof. Dhawan who put ISRO on a sound footing was himself a first class aeronautical engineer. All things taken together, the prevailing culture in ISRO was rather different from what obtained in the DRDO. Coming back to basic research, it is a real pity that it is rather weak in DRDO. What I am trying to say is that the time

has come for the national labs of India to sink their differences and work together. Whether you like it or not, you need applied research for good basic research, for without applied research you cannot get the scientific tools you want. Our people engaged in basic research are cocky because they can import instruments as they like. Relying totally on imported instrumentation cannot make a big country like India into a first class nation. If you have the talents plus the tools, you can follow your own path. If you don't have the tools, you have to take your ideas to others. That is not going to work unless the idea is super great. That would then push us into doing what others are already doing, and in this process we would be several months late because it takes time to import, etc.

A country like India with a population of 1.2 billion which is soon going to be the most populous country in the world cannot and should not allow itself to be pushed into a subordinate role. If you think about it, we are like Europe. Why then can we not be as forward in science and technology like Europe? Remember, after the war, most of Europe lay in ruins. But through hard work and cooperation they have come back. There is a great lesson to be learnt there.

We have a lot of potential, far more than we realise. What I saw in PFBR earlier this day made my heart swell with pride. I tell you when this place was started with the name RRC, I was told that the job of the Centre is to design a PFBR and then build it. That was way back in 1972. Frankly speaking, back then few dreamt, it would happen in our life time; may be some time far in the future. I never thought I would live to see the PFBR near completion but I did!

The PFBR is really a fantastic achievement, particularly at this point of time when America has abandoned fast reactors, Europe has put them on hold and Russia is struggling with its economy. What impressed me most about the PFBR is that every system, be it the sodium system or the reactor design or the control system (which, by the way has been designed by EIL which I helped to set up in the early days) – they have all delivered the goods in a fantastic manner. Every single division of the original RRC has made a monumental contribution to PFBR and this is something anybody can be proud of. Your generation has done it and you really need to be proud of it because each of you have contributed to this in your own way and chosen to live close to it.

When I was being taken around the PFBR I told Mr. Chakravarty,"I wish somebody would make a film documenting this historic achievement." Everyone who described or explained something connected with the reactor spoke with a lot of confidence. One thing I learnt at BARC was confidence. When I came out of Madras University I knew nothing, literally; my knowledge of Physics was very limited – they taught us very little back then. Here I must mention that when Prof. C. V. Raman was in Calcutta, he was accused of bias because he often took students from Madras. Defending himself Raman said, "Madras University is a very good university. It doesn't teach any Physics. So its students come to me with empty heads and I fill those heads with physics. It is difficult to fill a head that already is full with junk; empty heads? That is a different matter!"

I can testify to the fact that it was true with my case; I did not know a damn thing in Physics. Then suddenly I was told to work in atomic energy, exactly 10 years after the first atom bomb had been dropped. Dr. Rammana told me to build a gridded ion-chamber. I have never seen one and was wondering what to do. It was like being thrown to the wolves; the only thing I could do was to struggle and survive. That is what really gives one confidence – grappling directly with real-life problems. Soon you develop the feeling – if that fellow in Russia or America or whatever could do it, why not me? It is that confidence that helped me to go to all sorts of places and do whatever it is I have done. I could see a lot of confidence today both at IGCAR and PFBR and this is what would make us a great country.

Sir, what do you think is the necessary quality of a researcher?

A good researcher must be always asking questions. I always ask questions to myself. For example, if some sugar is accidentally spilt in the room, tiny ants come in hundreds from somewhere to eat and carry away the sugar. Now I know the temperature of the room; so I can calculate how many sugar molecules would sublime and what would be the amount of sugar molecules in one cubic meter of air. If this number is calculated, one would find it is ridiculously small. Keep that in mind and now turn to the ant. It is so small and its nose with the sensor inside has got to be even smaller. The question now becomes: "How does such a tiny sensor detect the minute sugar present in the atmosphere?" I have always wondered about this. So a researcher has to first wonder. When he starts wondering, all sorts of questions would spring up, which have to be answered one by one. This is what leads to discovery. At times, you need to be a bit crazy; that sure would create problems in your marriage but it is ok if good science finally comes out it!

Sir, do you think we lack behind in Basic Science, in terms of number of paper published and the originality of ideas? In case we lack, can you please suggest some steps to overcome?

You see the first thing is that we must stop trying to always follow a crowd. When our research reduces to following the fashion, we are at a disadvantage since we are already 'late for the party'. Somebody elsewhere gets an idea, and it gets actively worked on for months. We then read about it and try to do something in that area. What can you do coming in late, unless you are damn lucky? If we are already in the big league, then it is a different matter. But when we are not quite there, we need to work out our own strategy to achieve excellence. Among other things, we must try and do what others are not too much bothered about. I know it is a bit tough, but then all the crazy guys do that; so why not be a bit crazy?! If you have a problem you are thinking about it all the time, then sometime or the other, you will subconsciously arrive at the solution, and that becomes the moment of intuitive discovery. For this, intense concentration is required and you must be obsessed with the problem.

Take MRI. I am simply amazed by MRI, and my reason is as follows. Nuclear Magnetic Resonance was discovered in 1948 by Felix Bloch from Stanford University and Edward Mills Purcell from Harvard; later they shared the Nobel Prize for that discovery. When I joined TIFR, I saw the NMR instruments of those days. My late wife used to work in NMR. In TIFR, they built many NMR spectrometers – there was no other option. It was only later that they started to buy machines after they became available in the market.

Let me now turn to MRI. This basically exploits the NMR of protons, of which there are any number in the human body. The MRI is based on proton NMR, but the remarkable thing is that proton NMR has been taken all the way from a lab tool to a medical technology. That has been possible by adding four or five additional skills to proton NMR. And that is where ingenuity comes in. MRI has been created by adding to NMR several other skills and creating an algorithm which translates the signals from the millions of protons in a human organ into a medical diagnostic signal. Basically, it is all about value-addition. So if you get into a crazy team where there is a convergence of many bright ideas, you may be able to pull off great things. Such work, however, requires a proper environment. Great labs provide such an environment. That comes from a visionary combination of bright people and enlightened management.

When Prof. Carlo Rubbia discovered the W particles, he knew exactly what he wanted to do. He wanted to arrange for a proton to collide with an anti-proton. However, he lacked a machine where he could do that. So he went to CERN and told the then Director Sir John Adams, "I want to convert the machine you have just built into a collider." Sir John replied, "Don't be silly! We have just built a new synchrotron and there are so many experiments waiting to be done. "Prof. Carlo Rubbia replied, "OK. I will sell this idea to Americans. When the experiments are done and the Nobel Prize is awarded, America would get a share of the credit!" What I am saying is that Rubbia's idea was so good, he could sort of blackmail CERN! Adams then said, "You win, but we don't know a thing about colliders." That was when Rubbia talked to Van der Meer, a brilliant electronic engineer and together they did everything. Eventually, Rubbia discovered the W^+, W^-, and Z^0. So it is a question of ambience; the lab must encourage you to a certain extent and for that, the lab must have an enlightened policy. In BARC of earlier days, we had such an environment and we could talk freely with one another. Presently, those things are not so common, indeed even in America, since fierce competition is the name of the game. If you have a rich and vibrant environment where everybody can talk freely to one another without fear of getting one's throat cut, then great things can happen. Above all, you must have great curiosity and intense passion.

I once happened to meet a Srilankan scientist in the famous Jet Propulsion lab in California. This man had developed an infrared sensor that can detect up to 10^{-14} watt difference in heat, i.e., if a satellite is looking at the ground and there is a spot in the ground of 5 square meters, whose temperature is different from the rest of the ground by this tiny amount, this sensor could detect it. It was being used for secret work like spying on who is firing missiles and all that. That is not the story; the story is that this scientist now wants to use this sensor in biology.

You see cancer starts with the misbehaviour of cells. To start with, all cells behave normally. And then suddenly, for reasons we still do not understand in full, one cell begins to behave abnormally. Now our cells are very good at detecting invaders and when they do, they send agents to fight the invaders. But when a friend becomes a foe, the cells are not able to recognise. That is what gives cancer a great advantage. By the time the body starts having problems at the macro level cancer has already got a good foothold; that is what makes fighting cancer so tough. To get back to what I was saying, when misbehaviour starts, the metabolism or the energy production in the cancerous cell would be different from that of neighbouring normal cells. The scientist I referred to already has a detector with terrific sensitivity. To use it to track cancer in the very early stages, he is now trying to adapt his detector so that it can be introduced into the body and locate where the problem is erupting. The net result is that with this new device, cancer could perhaps be detected at a very early stage. If that happens, it would be a great leap forward in fighting cancer.

My point is simply the following. This fellow was given an assignment that had something to do with spying from space. But once he had a detector, he began thinking about an entirely different application. In other words, once you have a terrific idea, you must look to see where all you could use it.

Years ago, there was a journal which I used to get free. It was published by the Lawrence Livermore National Laboratory and was a monthly. Nowadays they have stopped printing it, but if you go to the internet, you can easily see the e-version which is still being published. By browsing through that journal, I am sure you would not only get to know many things outside of your field but also get a lot of new ideas. This is one way of window-shopping for ideas – look outside of your backyard.

You have written about Dr. C. V. Raman, Dr. Meghnad Saha, Dr. S. N. Bose and others. Whom do you think has made important contribution to Indian Science?

First of all, I hope you bought those books because if you have, there would be royalty payments which go to a charity! Listen, it is not like picking out a winner as they do with Oscar Awards. The scientists you have named all had different personalities and they also had a different way of doing things. If you take S. N. Bose, he was a dreamy man surrounded by cats and often lost in his music. He did many things but got little credit for it; however, Bose never bothered about it. He was great in his own way.

Meghnad Saha made a fantastic discovery in astrophysics, which the Americans used extensively to classify stars properly for the first time. As was said, they used his result but he was not invited to the party. What is important, as Chandrasekhar has noted, is that at the time all these people suddenly appeared to come out of nowhere. The truth is at that time there was a great nationalistic fervour in the country, especially in Bengal.

This resulted in an intellectual renaissance, which aroused the whole of Bengal. There was also a spiritual awakening, thanks to Ramakrishna Paramahamsa, Vivekanada, Aurobindo and so on. Arts, literature, culture, etc., got a big boost. Chandrasekhar said that they were all swept by that fervour and began to do things. Competition was not like what we have today, and if you had the mind and determination you could do things.

Today, things are very different. Even so, if one is determined to succeed and tries hard, something is bound to come out of it. The least one can do is to help others to gain in confidence so that they shine – that is what working in public interest is all about.

When Sir J. C. Bose started the Bose institute, just two doors away from Kolkata University, it was modelled after the Royal Institution in London, which was founded by Faraday. There is a board there saying "*any discovery in this Institute would, in the tradition of this country, be offered to the whole of humanity.*" In other words, no discovery would be patented. Today, science has become quite mercenary. In olden days if you solved a crystal structure and sent a paper to Acta Crystallographica, you had to give the atom coordinates. Basically solving the crystal structure means finding out the coordinates of all the atoms in a unit cell.

When I was in ANURAG, Dr. Athithan who earlier used to work here in IGCAR was doing 3D modelling using computers. At that time, Dr. Ramanadham of BARC came to see me and he told me that while in Seattle, he had solved the structure of a complex biomolecule. I asked him if he had the data, and if so whether he would share it with us so that Athithan could show the 3D structure of that molecule on the computer. Dr. Ramanadham replied, "You know, this structure is patented and the atomic coordinates are a secret." I assured him that even if I tried to sell it in Charminar in Hyderabad city, nobody would buy it. But Ramanadham was not willing to share data because the University in America had patented the molecule as it was a potential anticancer drug. Nowadays, you can publish a paper in Acta Crystallographica, without giving the atomic coordinates. I am mentioning all this to compare with the noble intentions with which Sir J.C. Bose founded his institute, insisting that sharing knowledge is the tradition of this country. Whenever we work and share the fruits with others, everybody would be benefited in the long run. The more one tries to be selfish, the more would be the problems society would have to face.

In present day America there are groups called patent trolls, which are nothing more than mafia. Suppose like Edison you have a wonderful idea and you patent it. One of these companies would file a suit against you on the ground that you have stolen an idea from someone or the other. Everyone knows that it is rubbish, but if you have to prove that the other fellow is telling a lie, you have to go to court. Now you are a young entrepreneur trying to come up and you have no money; in fact, you are hoping to make money with your invention. But there is a case filed against you. To fight it and to prove yourself you have to hire a lawyer. The mafia has a lot of money and it would hire a very smart layer, which you cannot do. When the case comes up in court, the smart lawyer outwits your lawyer and you are in a fix. The mafia then compels you to tell the court that you agree to an out-of-court settlement. They would then make you sell the patent to them for a small sum, after which they would lease the patent to a big company and earn huge royalty; maybe, they would give you a few crumbs now and then. That is how terrible even innovative science has now become.

What is it about spirituality that often a physicist gets attracted ?

The connection between physics and spirituality is a kind of long story. It all begins when physics approaches metaphysics; one may say that physics is then at the door step of spirituality.

In my view there are, what might be called, levels of rationality. As far as physics is concerned what you call rational, is logic within the framework of space and time. Now there is good evidence that the universe in which we live was born about 13.8 billion years ago. Whatever is discussed as physics relates to things happening in space and time, both of which came into existence only after the birth of our universe. There are things that could have happened beyond space and time. For example, the question can be asked:"What led to the birth of our universe ?" Physics cannot tell you; at best, it can speculate. Roger Penrose has done precisely that and made an intelligent guess. What he says in his book "*Cycles of Time*" is that, in his model the mother of our universe would have left her finger prints on the universe we live in. This is like saying we get some part of our genes from our mother. Penrose is looking for genes from the previous universes and says they would leave their imprint on the cosmic microwave background(CMB).

In a sense, Roger Penrose is speculating about a domain which is beyond physics as we know it. We don't know what laws apply there, whether Newton's laws work or not. There are many things beyond the universe and those are things on which one can have a rational discussion even though we cannot quantify the discussion. My point is that one can discuss about things beyond space and time and still be rational. If you read Vivekachudamani of Shankara, it deals with transcendental issues in a highly logical manner. It is not nonsense; on the contrary, there is profound logic of a certain kind, but it relates to a frame of reference that is beyond space and time.

Sir, can spirituality be taught ?

What do you mean by taught?

In the sense like what we do in schools.

While we can tell people about what is spirituality and so on, in the ultimate analysis, spirituality is really related to experience of a high order, higher than the usual sense experience. Even in the case of ordinary experience like seeing – and by the way, Schrodinger gives an interesting discussion of this – when a person says,"I see a red colour," it simply means his sense organs create a sort of sensation in that person to give him a unique

experience. Another man sees the same object and says, “I also see red.” There is no way of proving that both are seeing the same thing! True, one can wire up the two persons with all sorts of complex instrumentation including functional MRI. But at the end of the day, experience is a dimension beyond physics since it is purely subjective; people do not appreciate this. In the same way, there is a realm of experience that completely transcends the senses. That transcendental experience is not only beyond the senses but even the subtle entity we usually refer to as the mind. Indeed such experience cannot even be fully described because it is beyond the mind and words come from the mind. Yogis and saints have had such transcendental experiences and they are referred to as mystical experiences.

In earlier times, such experiences were not dismissed. In fact, back then the subject of philosophy included both the feeling aspect as well as the motion aspect. It was only from Newton's time that the feeling part was totally decoupled from the motion part, and that is how modern physics has moved far from metaphysics and spirituality.

Brian Josephson who won the Nobel Prize for discovering superconducting tunnelling says that if you want to explain life via physics, you have to change the paradigm of physics as was done when quantum mechanics was developed. This time, one has to bring in consciousness and things like that. That is a very important point and we have to understand that there all these things that cannot be simply dismissed or rubbished.

Freeman Dyson puts it all in a simple manner, though it is about physical reality and not transcendental reality. He says that the world of atoms can be completely explained using quantum electrodynamics. One starts with a Lagrangian that is consistent with all the requirements of quantum electrodynamics. One then “churns the equations” and in the end get electrons, positrons, X-rays, gamma rays and everything. But, says Dyson, the quantum field one started with is totally abstract. He adds that when he sees a beautiful tree or a beautiful mountain, he is astonished how come abstract fields look like this! Is quantum field theory real or what I see is real? This is rather like a story where Janaka, after suddenly waking up from a bad dream asks Sage Vasishta,“was that real or is what I now see real?” Our sense organs give us a perception of the world we live in and nature has endowed us with this perception to help us survive. What we do is to take this perception and call it reality. So the question becomes: “What exactly is physical reality?”. That in fact was the subject of the famous debate between Bohr and Einstein - what is physical reality. Bohr said reality is created by the act of observation. Einstein replied, “Nonsense! Do you mean to say that moon does not exist when you don't look at it?”

There is a lot of history to this. When you go to that level, you get into more and more of complications and it looks like physics will have to someday come to terms with consciousness. Right now, we don't know how to do it. When we do that, physics and spirituality would be on talking terms.

Spirituality really belongs to the domain of higher-order experience and cannot be taught, although a lot of instructions can be given about how to discover one’s true nature and have a mystical experience. Simply put, it is all about discovering the nature of oneself beyond one’s body and one’s mind.

Sir what are your expectations from IGCAR in the future?

Who am I to expect anything from IGCAR? You should ask yourself what is that you want to do. You should tell yourself, “This is my target and I am going to reach it.” Why do you ask me? You have earned the right to set your expectation, and there is no need to let another person call the shots.

What is your advice for younger generation?

This is a tricky question. How can I give advice when I am far remote in generation and time? I don't want to give any advice. All I would say is, become deeply involved in what you are doing and enjoy it. Then automatically you would find things falling in place. If you want any specific suggestion, I would say enjoy your work and throw yourself at it whole heartedly.

You look at Janwadhkar and Radhakrishnan. The latter is a diabetic and see how hard he works. In my time, I have had a lot of arguments with Radhakrishnan, but seeing what he has done, I take my hats off. It is a very difficult piece of work and far from trivial. He and Janwadhkar have made all the devices, done the lithography and so on. They have managed to fund and set up a lab. As compared to a commercial SQUID-based MCG machines which have only 7 channels, the machine built here has 34 channels. Together, Janwadhkar and Radhakrishnan have built a state-of -the-art instrument. The problem is, he is not able to get a doctor to make a full medical assessment of his instrument, which is a bit unfortunate. Moreover, he needs a good computer scientist (like Athithan) to write some algorithms to make the machine really versatile. I tell you that you are setting on something big there and such an achievement comes out of real passion. You know in America, Siemens would have bought it. I wish you people would get in touch with a research-minded cardiologist – that would take you places. I also suggest that you go to the net and download all sorts of ECG patterns. This way, you can have a ready reckoner for making quick diagnostics. I would say you have got a better machine than what is commercially available. I warn you to be careful because market can easily throttle you. I am happy that the whole thing is indigenous; it is a great achievement.

From SQUID-based MCG to PFBR, my day has been most rewarding, and I don't even need dinner! My cup of joy is full. All I can do is to pray for your welfare and goodness. Since all of you are doing wonderful work, there is really no need for me to give any advice! All the best!!

The team:
Ms. Diptimayee Samantray, Ms. Gurpreet Kaur, Ms. Rimpi Dawar,
Shri Anindya Bhattacharyya and Ms. K. Saipriya

Small Punch Creep Testing Technique for Development of Creep Resistant Steels

Small Punch Creep (SPC) is an innovative testing technique to evaluate creep properties of materials. Compared with conventional creep testing, SPC testing technique has several advantages. It is material non-intensive and so requires only a small amount of material for carrying out the tests. The test duration is also relatively short. Potential applications of this technique include optimisation of chemical composition for development of creep resistant materials, characterisation of creep properties of narrow heat affected zones of weld joints which is not feasible with conventional creep tests, and assessment of structural integrity of components without impairing the performance of the component. The major difference between this testing technique and conventional creep test is that the mode of loading is bending and stretching in SPC tests, unlike tensile mode of loading in conventional creep tests.

Testing Methodology

In SPC testing, a small square specimen of typical size 10 x 10 x 0.5 mm is loaded at high temperature using a spherical ball punch made of ceramic material at a constant load, and the test is continued till the specimen ruptures. Figure 1 is a schematic of the SPC specimen in contact with the ceramic ball and undergoing bending into a receiving hole of the specimen under a load F_{sp}. R is the ball punch radius, t is the thickness of the specimen, h is the radius of the receiving hole, ϕ is the angle between the loading axis and the normal to the specimen surface at the point of inflection and θ is the angle of bending. The deformation begins with elastic bending of the specimen when the ball initially contacts the specimen. Yield occurs in the highest stressed region due to the bending action. This is followed by plastic bending when the yield front expands through the specimen thickness and also radially outwards. The mode of deformation then changes to membrane stretching and the yield front expands beyond the region of contact

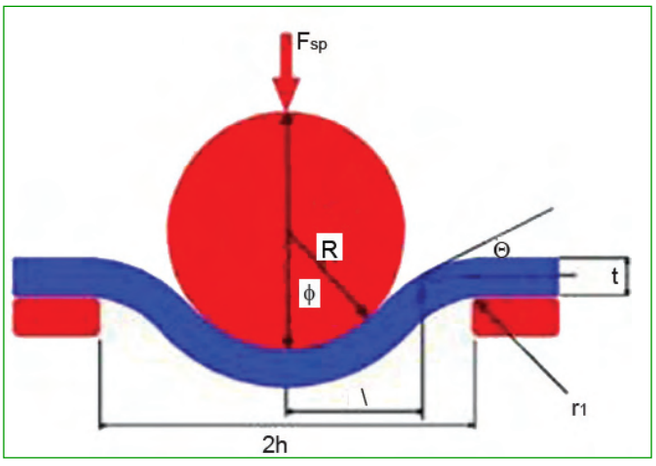


Figure 1: Schematic of the SPC specimen in contact with the ceramic ball during SPC test

between the specimen and the ball punch. The stress state thus changes to biaxial conditions. Finally, the specimen undergoes local thinning leading to fracture. The resultant SPC curve is characterized by loading strain, primary, secondary and tertiary creep stages.

Studies towards development of nitrogen enhanced 316LN SS

SPC tests were carried out at 923 K under argon gas atmosphere on 3 heats of 316LN stainless steel (SS) containing 0.07, 0.11 and 0.14 wt.% nitrogen using a dedicated SPC machine of 2 kN load capacity under compression loading. Silicon nitride spherical ball of diameter 2.38 mm was used for applying the load. Tests were carried out under constant load control mode. The displacement was measured using a pulse encoder.

Figure 2 is a typical SPC curve obtained at a constant load of 300 N at 923 K (650 °C) on 316LN SS containing 0.11 wt.% nitrogen.

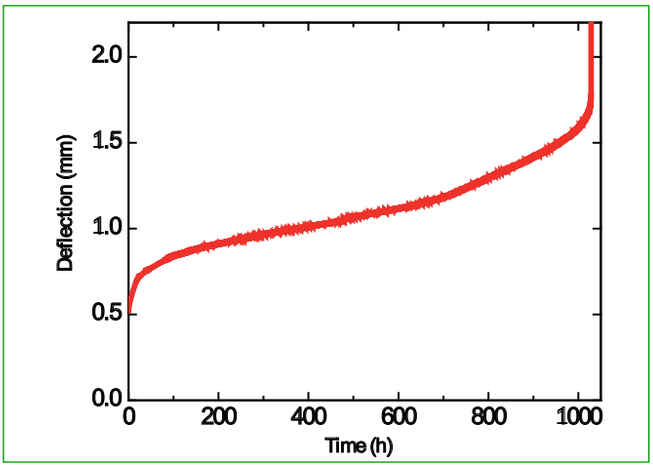


Figure 2: SPC curve obtained on 316LN SS containing 0.11 wt.% nitrogen at 923K (650 °C) under a load of 300 N showing three stages of SPC curve

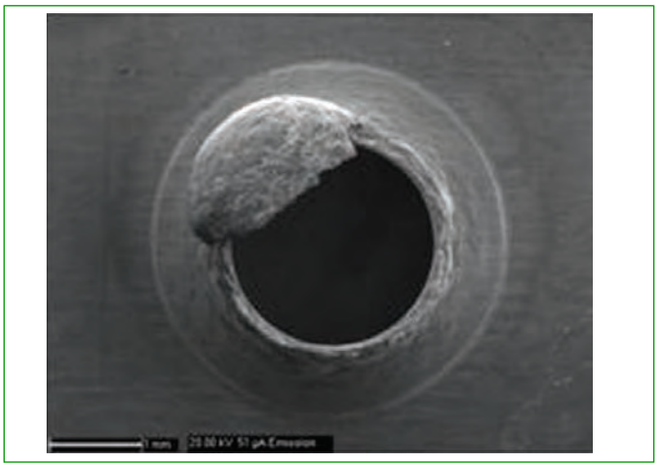


Figure 3: SPC sample after fracture

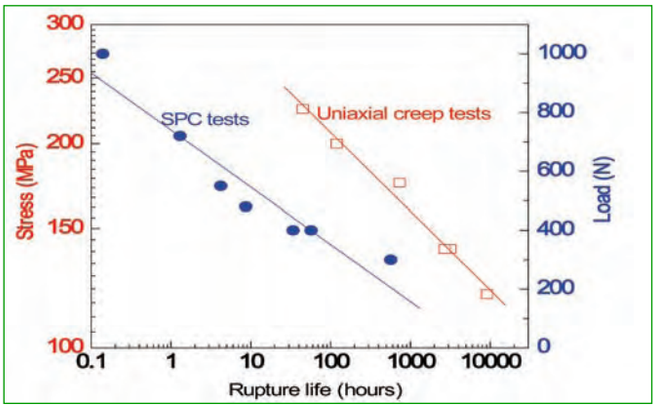


Figure 4: The stress versus rupture life plot for conventional creep tests

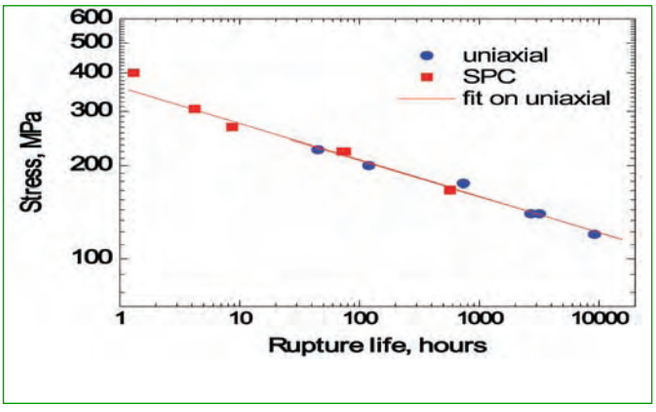


Figure 5: Correlation between SPC and uniaxial rupture life for 316LN SS at 923 K

It shows well defined primary, secondary and tertiary stages of creep. In the primary region, bending is the dominant mode of deformation whereas in the secondary and tertiary regions, membrane stretching is the dominant mode of deformation. The rapid increase in deflection rate in the tertiary region is mainly on account of the localization of deformation and nucleation and growth of creep cracks. The SPC experiments were carried out at different loads. Figure 3 shows a typical scanning electron micrograph of a fractured specimen. The SPC test is automatically terminated before the last ligament of the stretched cup separates as shown in Figure 3. Rupture life increased linearly with decrease in applied load (on log-log scale) as shown in Figure 4. SPC results were found to obey the Monkman-Grant relationship which relates the variation of minimum deflection rate as a function of rupture life. Validity of the Monkman-Grant relationship implies that from a limited number of creep tests, the relationship can be used to estimate the time to rupture at lower load levels if the minimum creep rate is known.

The SPC parameters like minimum deflection rate and rupture life showed the same kind of relationship with applied load, as in the case of uniaxial creep tests using bulk specimens. It is necessary to obtain a valid relationship between creep rupture data from SPC tests and data from standard uniaxial tests. Superimposed in Figure 4 are the data from uniaxial creep tests in the form of stress versus rupture life. Although a linear relationship was found to be obeyed by both SPC and uniaxial data (on log-log scale), there is no correlation between data from SPC and uniaxial tests. An empirical relationship derived from stretching membrane theory, which is used to correlate rupture life determined from SPC tests with rupture life determined from uniaxial tests and that is obeyed by several engineering materials is given by $F_{SP}/\sigma = K.R.t^2/h.D$ where F_{SP} is the SPC load, σ is the uniaxial stress, K is a geometrical constant, R is the ball punch radius, t is the thickness of the specimen, h is the radius of receiving hole and D is a ductility factor for the material in the test temperature and load range. Taking into account the material and the geometrical parameters, the above equation can be simplified to the form $F_{SP}/\sigma = \alpha$. Figure 5 shows the uniaxial and SPC rupture life data plotted in the same graph using the above relationship with a value of α=1.8 mm^2. It shows a good correlation of the rupture life data obtained from the two types of tests. The value of α was found to be the same for all the three heats. Hence SPC test is considered as a reliable small specimen testing technique to evaluate creep properties of materials.

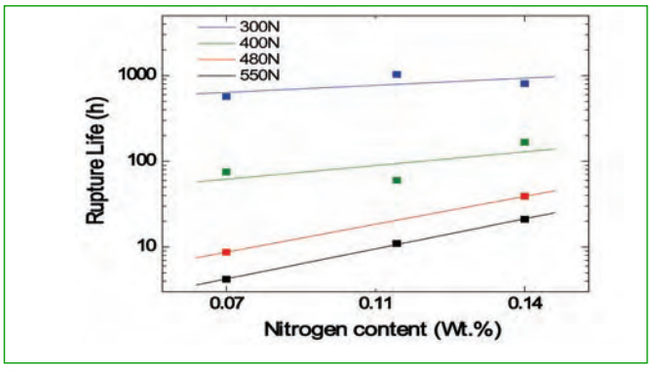


Figure 6: Increase in nitrogen increases rupture life; similar to the observations from uniaxial creep tests

SPC tests were carried out on 3 heats of material in order to study the effect of nitrogen content on creep behavior of 316LN SS. Figure 6 shows the variation of rupture life with nitrogen content at various applied loads. Rupture life increased with increase in nitrogen content. These results were consistent with the results obtained from uniaxial creep rupture tests which showed an increase in rupture life with increase in nitrogen content over the entire range of 0.07 to 0.14 wt.%, thereby demonstrating that SPC test is an excellent and innovative technique to study creep properties of multiple heats in relatively short test durations and thus optimise the chemical composition in order to develop creep resistant steels.

Reported by M.D. Mathew and Colleagues
Mechanical Metallurgy Division
Materials Development & Technology Group, MMG

Studies on Mitigation of Sodium Fire

Sodium Fast Reactor (SFR) is a promising option for the development of fast neutron reactors, which is well known owing to its wide development since the 1950's, throughout all the countries involved in the development of nuclear power plants. The development of SFR has been possible thanks to the attractive nuclear, physical and even some of its chemical properties. Sodium is the most common of the alkali metals. Sodium is used as coolant in Prototype Fast Breeder Reactor (PFBR) and will continue to be used as coolant for the several fast reactors in future. Use of large amount of sodium in the primary coolant system is advantageous from the standpoint of safety, because of high heat capacity of sodium and natural circulation flow. In spite of the above positive features, the chemical reactivity of sodium particularly with air and water is of great concern, in case of sodium leak from the components/pipings. Operating experience indicates that the sodium leaks can not be completely ruled out. Safe disposition of huge amounts of radioactive sodium during decommissioning stage would call for high investment, operational cost and complex technologies. Also, there are a few structural mechanics problems related to sodium, viz. thermal striping and thermal fluctuations, which severely affect the structural integrity of adjoining structures. These are the critical issues, responsible for slowing down of sodium fast reactor development and forcing the researchers to study alternate coolants, such as gases (helium and CO_2) and alternative liquid metals (lead and lead-bismuth). Despite these facts, the problems have been overcome through suitable design measures, for e.g. the quantity of sodium used in the reactor is optimized by choosing possibly minimum size of reactor and heat removal systems through innovative design concepts. The major limitation of sodium is its opaqueness, which poses challenges for the in-service inspection of reactor assembly internals and fuel handling operations. Fuel handling problems have been experienced in FBTR, JOYO (Japanese reactor) and BN type reactors (Russian). In this regard, indigenous development of vibration measurement systems and under sodium viewing play key role. The under-sodium scanners are also essential for the successful fuel handling operation without having any risk of damage of fuel bundles as well as fuel handling parts.

The sodium fast reactor has accumulated over 400 reactor years of operating experience. The operating experience has indicated occurrence of small sodium leaks within steam generator building where almost all the secondary sodium circuit is housed, in many reactors. There were 32 leaks in Phenix and 27 leaks in BN 600 reported, but they have not affected the plant availability seriously. The consequences of small leak are minor sodium fire and corrosion of stainless components and thermal insulation materials. Figure 1 depicts the nature of corroded piping wall surface due to such reaction. Reliable detection of very small leaks remains to be still the most challenging activity. Next, relatively large leaks order of a few tonnes occurred in the reactors such as Phenix, Monju and BN-600. The consequences of these leaks are the generation of high temperature and pressure within the building, high degradation of concrete due to sodium concrete interaction and possibility of release of excess aerosol to the ambient (allowable value is a few mg/m^3). In order to address the concern on sodium fire, several basic research and engineering studies are being carried out at IGCAR to understand the safety consequences of sodium fire. Experimental facilities such as MINA (Mini Sodium fire facility), SOCA (SOdium-CAble fire facility) and SFEF (Sodium Fire Experimental Facility) were constructed and commissioned to study small, medium and large scale sodium fires. Experiments on burning of single sodium droplets were carried out to develop / improve and validate containment codes. In order to mitigate the effects of sodium fire towards enhancing the confidence on sodium safety among designers, regulators and public, systematic R&D programme is being carried out at IGCAR. This article presents some important highlights of the activities related to mitigation of sodium fire effects.

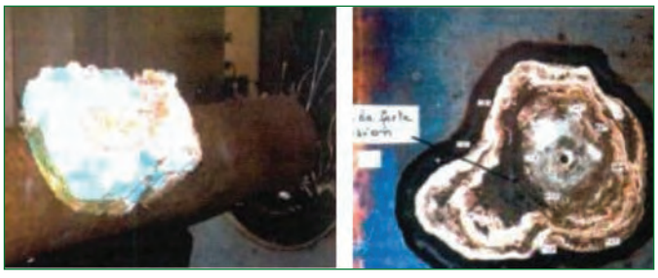


Figure 1: Sodium insulation interaction and corrosion of stainless steel pipe

Investigation on Plugging Characteristics of Small Leaks

In order to detect sodium leaks from the pipes in case of small cracks, very sensitive instrumentations are provided, e.g. wire type leak detectors are wound around the surface of the pipes, enclosed by thermal insulation layers. The minimum leak rate that can be reliably detected with the current technology at IGCAR is about 200 g/h. In order to quantify the consequences of leak below this value, several tests were conducted to understand the plugging characteristics of sodium when it is in contact with the oxygen available in the atmosphere. Towards this, a dedicated innovative experimental setup was built. Stainless steel pipes with 0.3 mm diameter pin hole were employed. The results show that the leak rate is a function of temperature, pressure and sodium purity. Leak rates are found to be random and the average leak rates are in good agreement with the theoretically calculated values. Conditions for unplugging have been established in terms of temperature and

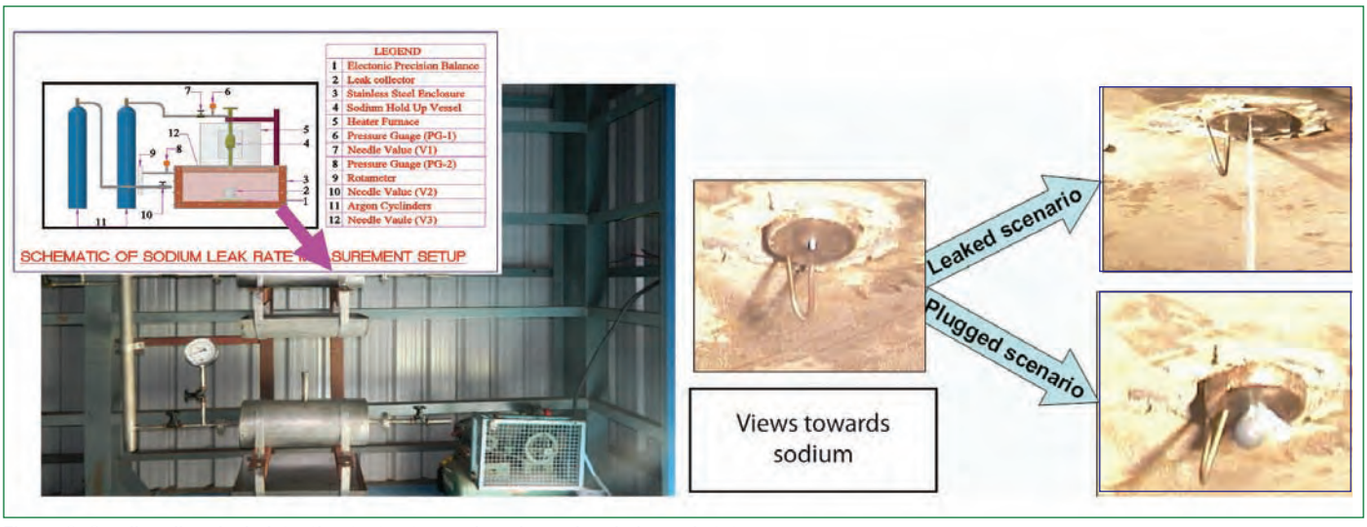


Figure 2: Small sodium leak detection test setup and unplugged and plugged states

pressure. The condition for no plugging of sodium was found to be above 290°C in conjunction with 4 bar pressure. The test set-up plugging and unplugging status are depicted in Figure 2. These results are useful for the design and operation of low leak detection techniques.

Qualification of Leak Collection Trays (LCT)

In order to mitigate the effects of medium and large sodium leaks from the pipes, leak collection trays are provided just below the pipelines all along their length. A schematic of complete leak collection trays system is shown in Figure 3. The set-up has been housed in the Sodium Fire Experimental Facility at IGCAR. The experimental hall is 9 m long, 6 m wide and 10 m height with a volume of 540 m^3. This is made up of 450 mm thick RCC floor, walls and ceiling with a design pressure of 50 kPa(g) and temperature of 65°C. All the four walls and ceiling are provided with 50 mm thick insulation and the floor with 150 mm insulation of calcium silicate boards. In order to prevent caustic attack on the concrete and to facilitate thorough washing after conducting the experiments, inside of the wall is completely lined with stainless steel sheets.

Leak collection trays collects the leaked sodium in a hold up vessel, suppresses the sodium fire by oxygen starvation and guides the sodium to inert sodium transfer tank. Towards this, a network of carbon steel pipelines is laid out connecting all the leak collection traysto sodium transfer tank, with each pipe having a fusible plug. The plug separates air environment in leak collection trays and argon environment in transfer tank. Woods metal with low melting point (~70°C) is the preliminary choice for the fusible plug. Leaked sodium by virtue of its high temperature melts the plug and drains into transfer tank. Tests provided important feedback that called for a few minor design improvements in the leak collection trays system. With the improvements incorporated, the LCTs have been qualified. Figure 3a also shows the view of qualification tests and Figure 3b represents the curve showing

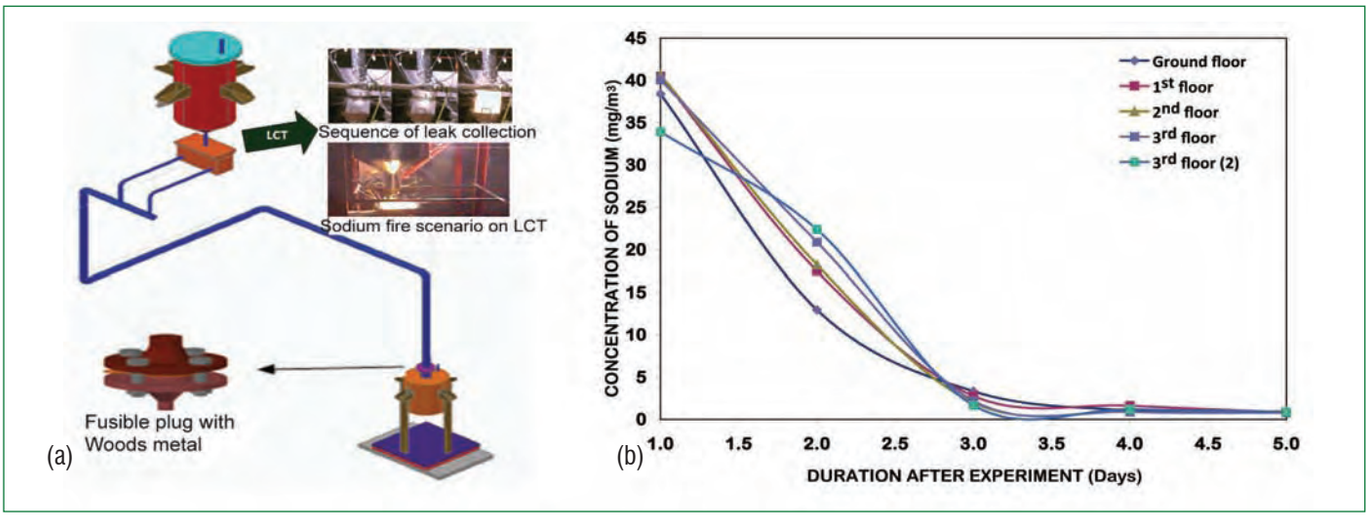


Figure 3: (a) LCT set-up and test sequence (b) curve showing aerosol generated during burning of sodium

Figure 4: Test sequence of flowing sodium fire scenario on concrete

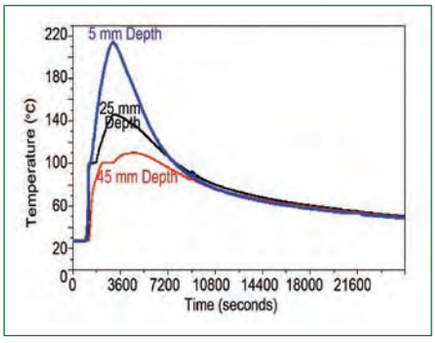


Figure 5: Temperature inside concrete at stagnant Zone

the aerosol generated during the burning of sodium (at time = 0) and subsequent settlement behavior. From this figure, the effective burning of sodium to get an practical idea on the cleaning of the building and equipment can be assessed.

Flowing Sodium-Concrete Interaction Studies

The leaked sodium from the pipe could attack the adjacent concrete wall surfaces and cause damage. A conservative approach is to provide stainless steel liners over the entire surface of the building (e.g. Monju reactor in Japan). This results in highly expensive solution. In fact the realistic scenario (perception) is the impact sodium flows on the wall surface and residential time is too short for causing any appreciable damage to the concrete. In order to validate such perception, tests are conducted using sodium resistant silica lined concrete blocks introducing slopes (Figure 4). During the experiment it was observed that at the stagnant zone, sodium flame temperature reached around 900°C and temperature inside concrete at 45 mm depth was 110°C which stabilized at 60°C shortly (Figure 5.) The outcome of series of experiment provides technical justification that there is no need of wall liners for the SFR.

Sodium-Cable Fire Interactions

Studies on sodium fire following secondary cable fire with polyvinyl chloride and flame retardant low smoke cables were carried out (Figure 6). Sodium spray fire event was observed only for 500 ms where as the ignited cable fire was prolonged for 18 seconds. The variation in electrical resistance measured before and after sodium fire experiment is included in Figure 6. It was observed that in case of polyvinyl chloride cables, the electrical resistance values decreased from 1.1×10^{10} to 2×10^{9} ohms whereas in case of flame retardant low smoke cables, the decrease was from 5.62×10^{10} to 2.24×10^{10} ohms. This indicates that flame retardant low smoke cables are more sodium fire resistant than the polyvinyl chloride cables.

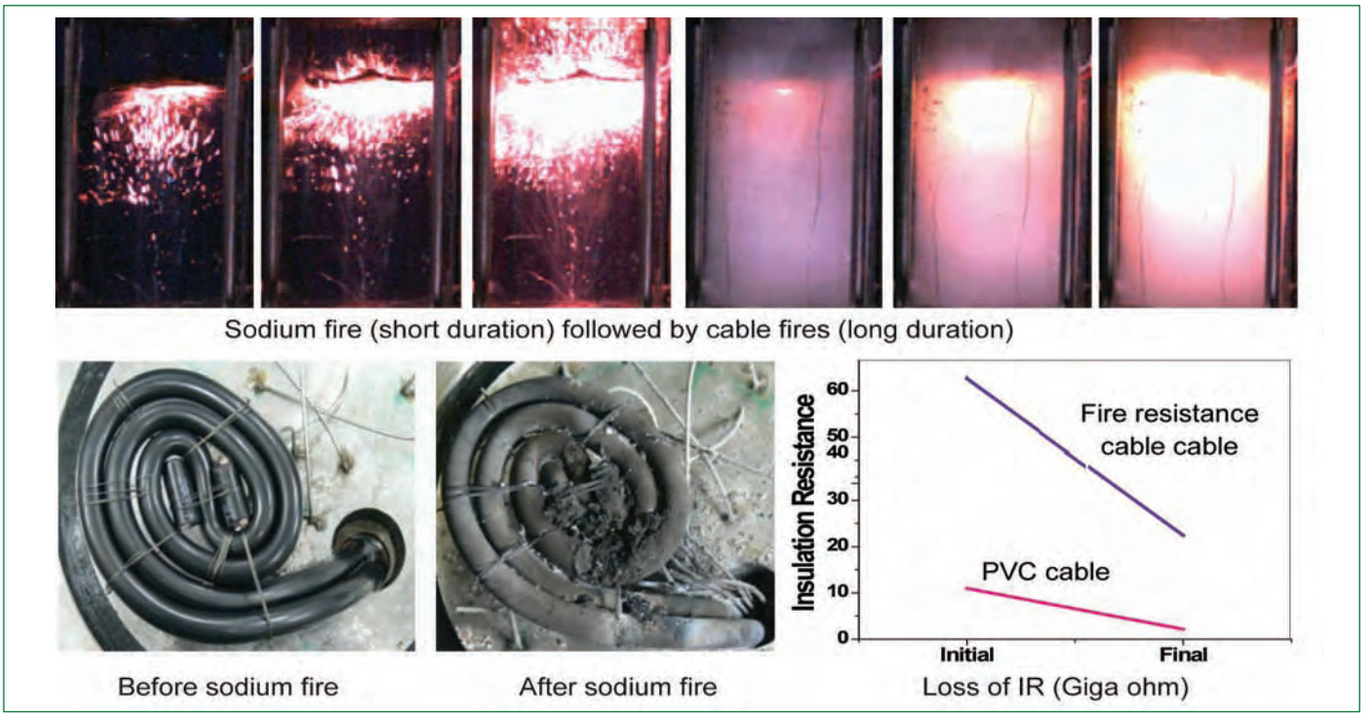


Figure 6: Highlights of sodium–cable fire test results

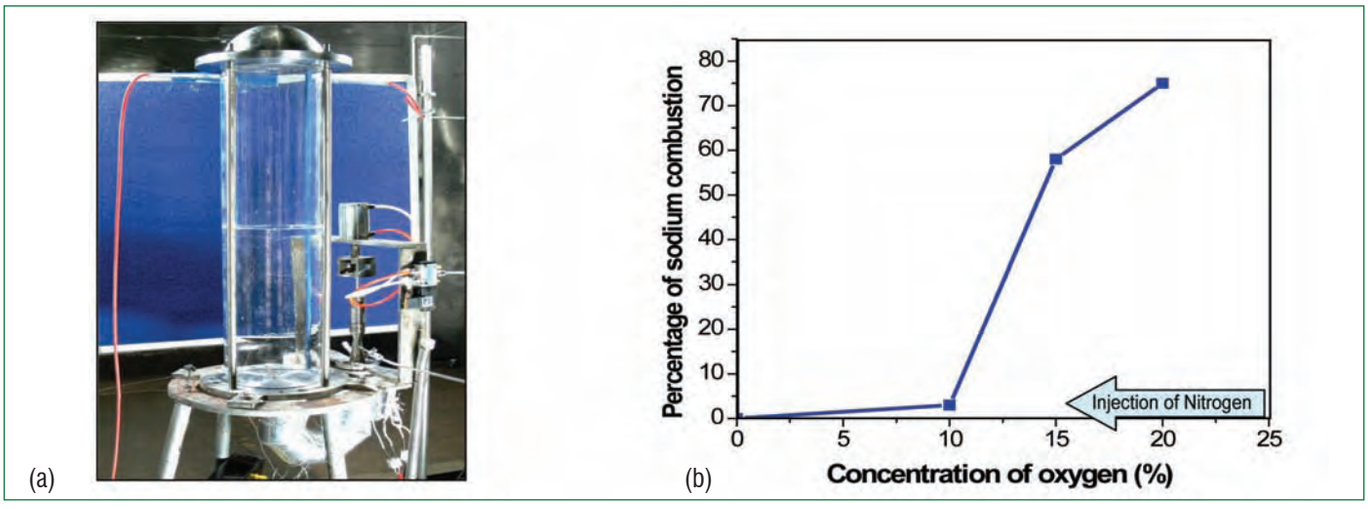


Figure 7: (a)Test setup for injecting Na and N_2 (b) effect of nitrogen injection on mitigation of sodium fire

Sodium Fire Mitigation through Nitrogen Injection

Injection of nitrogen into a closed chamber with the objective of gradually reducing the oxygen concentration, while sodium fire is in progress is studied (Figures 7a and 7b). It was observed that ignition of sodium fire at 500°C occurs only with minimum oxygen concentration of 4-5%. The percentage of sodium burnt as a function of oxygen concentration controlled by the injection of nitrogen was studied. The results will be useful to assess the performance and economic aspects of nitrogen injection system to mitigate the large sodium fire.

Carbon Microspheres for Sodium Fire Mitigation

Effectiveness of mitigation of sodium fire by applying carbon micro spheres over burning sodium is studied. Through this, the supply of oxygen for further combustion of sodium was suppressed. The indigenously developed carbon microsphere based innovative sodium fire extinguisher was tested on small scale sodium fire (Figure 8). It extinguishes sodium fire by covering the sodium metal surface and thus separating the metal from an oxygen source and then by conducting heat away from the burning sodium. The excellent flow characteristics, high thermal conductivity, chemical inertness and non-smoking properties of these microspheres highly promise as an efficient extinguisher for sodium fire. The sodium metal could be easily recovered once the fire is extinguished.

Based on various R&D activities, it has been concluded that the conventional as well as novel methods developed would function effectively to mitigate the small, medium and large sodium fires. This provides high confidence in safe operation of PFBR. Further, it can be stated that by close scrutiny and taking into account the advantages gained through sodium cooling, the SFR does not have any significant disadvantage. Rather, several attractive features of sodium can assure a positive trend in the establishment of safety of sodium cooled breeder reactor.

Reported by P. Chellapandi and colleagues
Reactor Design Group

Figure 8: Fire extinguishing potential of carbon microspheres

Young Officer's FORUM

Development of Diglycolamic Acid Based Extractants for Lanthanide(III)-actinide(III) Separation

Partitioning and transmutation is being considered as a viable strategy for the safe management of high-level liquid waste (HLLW). This is based on the separation of minor actinides and long-lived radiotoxic fission products from HLLW and transmutation into stable or innocuous products in advanced fast reactors. Partitioning of minor actinides from HLLW by the current practice, liquid-liquid extraction, usually results in the co-extraction of trivalent lanthanides due to the similarity in chemical and extraction properties of lanthanides and minor actinides . Since lanthanides act as neutron poisons that reduce the efficacy of transmutation process, separation of lanthanide from minor actinides or vice-versa is necessary prior to transmutation and the most challenging task due to the identical extraction chemistry of these elements .

Several schemes and extractants have been reported in literature for lanthanide (Ln) – actinide (An) separations. Among the various methods, the TALSPEAK (Trivalent Actinide Lanthanide Separation by Phosphorus Extractants Aqueous Komplexes) process is regarded as a promising technique for such separation. Basically, the TALSPEAK process exploits the differential complexing abilities of bis(2-ethylhexyl)phosphoric acid (HDEHP), present in organic phase and diethylenetriamine-N,N,N',N'',N'''-pentaacetic acid (DTPA) present in aqueous phase towards lanthanides and actinides. Dialkyldithiophosphinic acids and chlorosubstituted aromatic dithiophosphinic acids have also been studied for the selective extraction of trivalent actinides. In the recent past, pyridine and bipyridine based N-donor ligands have been studied for lanthanide–actinide separations and the bis-5,6-substituted-bis-1,2,4-tri-azinyl-pyridines were regarded as promising candidates for such separations from 1 –2 M nitric acid medium.

In our laboratory, we developed a new method based on

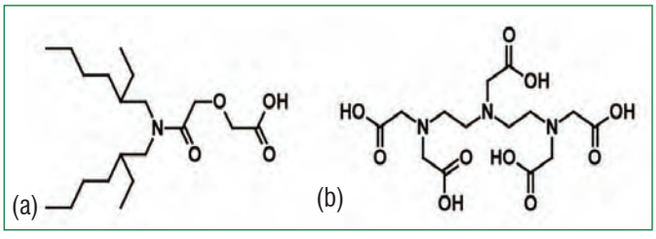


Figure 1: Structure of (a) HDEHDGA and (b) DTPA

Shri A.S. Suneesh joined Fuel Chemistry Division after completing OCES from 2nd batch of BARC training school, IGCAR campus. He did M. Sc. in Applied Chemistry from Cochin University of Science and Technology, Cochin. The areas of his research interest include lanthanide-actinide separation, minor actinide partitioning, magnetic assisted separation, ion exchange and molecular dynamic modeling. He has published about 10 papers in peer-reviewed journals and more than 20 papers in national conference and symposia.

bis(2-ethylhexyl)diglycolamic acid (HDEHDGA) as extractant and diethylenetriamine pentaacetic acid (DTPA) as aqueous complexing agent, for the mutual separation of lanthanides and actinides. Structures of HDEHDGA and DTPA are shown in Figure 1.

The diglycolamic acid is an acid derivative of alkyl-3-oxapentane, emerging as promising candidate for lanthanide-actinide (Ln-An) separations. Unlike the other reagents in-use, the diglycolamic acids are made up of CHON- atoms and they are completely miscible in n-dodecane.

The extraction behavior of Am(III), Eu(III), Zr(III) and Ru(III) in a solution of 0.1 M HDEHDGA/n-DD as a function of pH was studied from an aqueous phase containing 0.1 M citric acid. The distribution ratio (D_M) of metal ion was determined using equation 1. The separation factor was computed using equation 2.

$$D_M = \frac{[M]_{org}}{[M]_{aq}},\ M = {}^{241}\mathrm{Am(III)},\ {}^{(152+154)}\mathrm{Eu(III)},\ {}^{95}Zr(IV),\ {}^{106}Ru(III) \quad (1)$$

$$SF = \frac{D_{Eu(III)}}{D_{Am(III)}} \quad (2)$$

The results are shown in Figure 2. It is observed that the distribution ratio of Eu(III) and Am(III) increases with increase of pH, reaches a

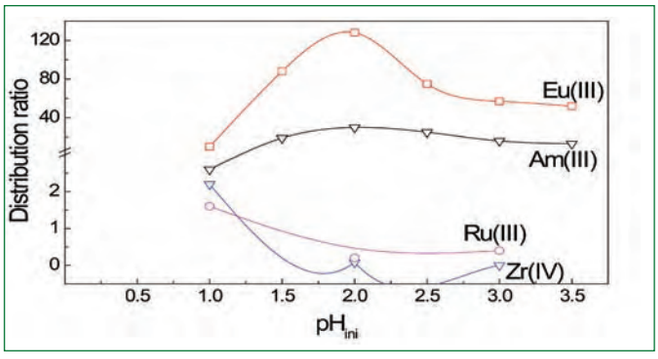


Figure 2: Variation in the distribution ratios of Eu(III), Am(III), Zr(IV) and Ru(III)

maximum value at pH 2, followed by decrease in distribution values. The extraction of Eu(III) is always higher than Am(III) at all pH values, which is characteristic to the diglycolamides and diglycolamic acid extractants. It is also observed that the distribution ratio of ^{106}Ru(III) and ^{95}Zr(IV) are quite low and they decrease with increase of pH.

Effect of DTPA

Aqueous soluble reagents are usually added to aqueous phases to augment the separation factor. It is desirable to retain the less extractable americium(III) in the aqueous phase by the addition of aqueous complexing agents. Diethylenetriamine-N,N,N',N'',N'''-pentaacetic acid (DTPA) have been reported as potential candidate for the retention of americium(III) in aqueous phase. Table 1 shows the distribution ratio of Am(III) and Eu(III) in HDEHDGA/n-DD as a function of DTPA concentration in aqueous phase. As expected, the distribution values of both the metal ions decrease with increase in the concentration of DTPA. It is interesting to observe that a maximum separation factor ~150 is observed, when the concentration of DTPA is 10^{-5} M. Further increase in the concentration of DTPA lowers the extraction of Eu(III) and Am(III) and decreases the separation factor thereafter.

Batch Studies

The conditions needed for the selective stripping of Am(III) from the loaded organic medium was optimized using citric acid and pH of aqueous phase. The experiments involved equilibration of loaded organic phase (containing Eu(III) and Am(III)) with aqueous solution containing 0.01 M DTPA and citric acid at pH 3. This procedure was repeated until Am(III) was completely stripped to aqueous phase. The results indicated that that the number of contacts needed for stripping of Am(III) and Eu(III) decreased with increase in the concentration of citric acid. At 0.025 M citric acid concentration, Am(III) was recovered quantitatively in seven contacts. However, this was accompanied by 63% stripping of Eu(III). To minimize the stripping of Eu(III), the pH of the aqueous phase was decreased from pH 3 at a constant citric acid and DTPA concentration of 0.025 M and 0.01 M respectively. Our studies indicated that Am(III) could be back extracted quantitatively from the loaded organic phase with negligible contamination of Eu(III) using the aqueous solution composed of 0.01 M DTPA-0.025 M citric acid at a pH of 1.5. Therefore, a stripping formulation composed of 0.01 M DTPA-0.025 M citric acid at pH 1.5 was proposed for the back-extraction of Am(III) from the loaded organic phase (0.1 M HDEHDGA/n-DD) for the mixer-settler run.

Mixer-Settler Studies with Simulated Waste

Based on the optimized conditions indicated above for extraction and stripping, the counter-current run was performed using a

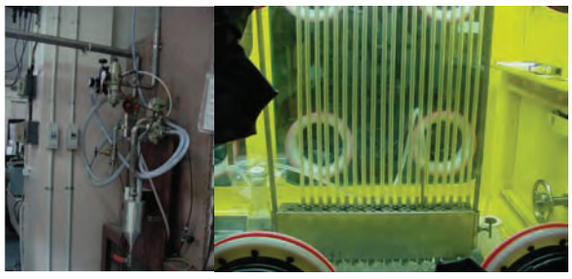


Figure 3: Mixer-settler used for demonstration run

20-stage mixer-settler. In this study the radioactive tracers $^{(152+154)}$Eu(III) and ^{241}Am(III) were used as lanthanide and actinide representatives respectively. The Eu(III) exhibiting higher distribution ratio than Am(III) is extracted quantitatively in two stages. Complete extraction of Am(III) is achieved in ~3-4 stages. The radioactivity remaining in the raffinate was determined to be negligible. The loaded organic phase was collected and Am(III) was stripped from the organic phase using 0.01 M DTPA-0.025 M citric acid at pH 1.5. Stage sample analysis revealed that the quantity of Am(III) remaining in organic phase decreased with increase in number of stages. About 70% of the Am(III) remained in organic phase in the first stage. This indicated that 30% of Am(III) was back extracted into aqueous phase. The stripping of Am(III) then increased with increase in number of stages. After 20 stages of stripping, only 4% of Am(III) was retained in organic phase, indicating that the recovery of Am(III) into aqueous phase was 96%. About 98% of Eu(III) was retained in the organic phase in all stages of a mixer-settler and only ~2% of Eu(III) was stripped to aqueous phase after 20 stages. The measurement of radioactivity of Am(III) and Eu(III) in lean organic and aqueous product also confirmed that the contamination of Eu(III) in Am(III) product was less than 2%, whereas the contamination of Am(III) in the organic phase was ~4%.

Ln-An separation with real-waste (CMPO raffinate obtained from minor actinide partitioning run)

A typical composition of a CMPO raffinate obtained after minor

Table 1: Variation in the distribution ratio of Eu(III) and Am(III) in HDEHDGA in n-DD as a function of additives at 298 K. Organic: Aq. phase ratio is 1:1 Organic phase: 0.1 M HDEHDGA/n-DD, Aq. Phase: [DTPA], pH=3

HDEHDGA			
[DTPA]/M	D_{Eu}	D_{Am}	SF= D_{Eu}/D_{Am}
10^{-5}	27.6	0.19	145
10^{-4}	4.9	6.5×10^{-2}	75
0.001	0.8	1.7×10^{-2}	45
0.005	0.2	2.5×10^{-2}	10

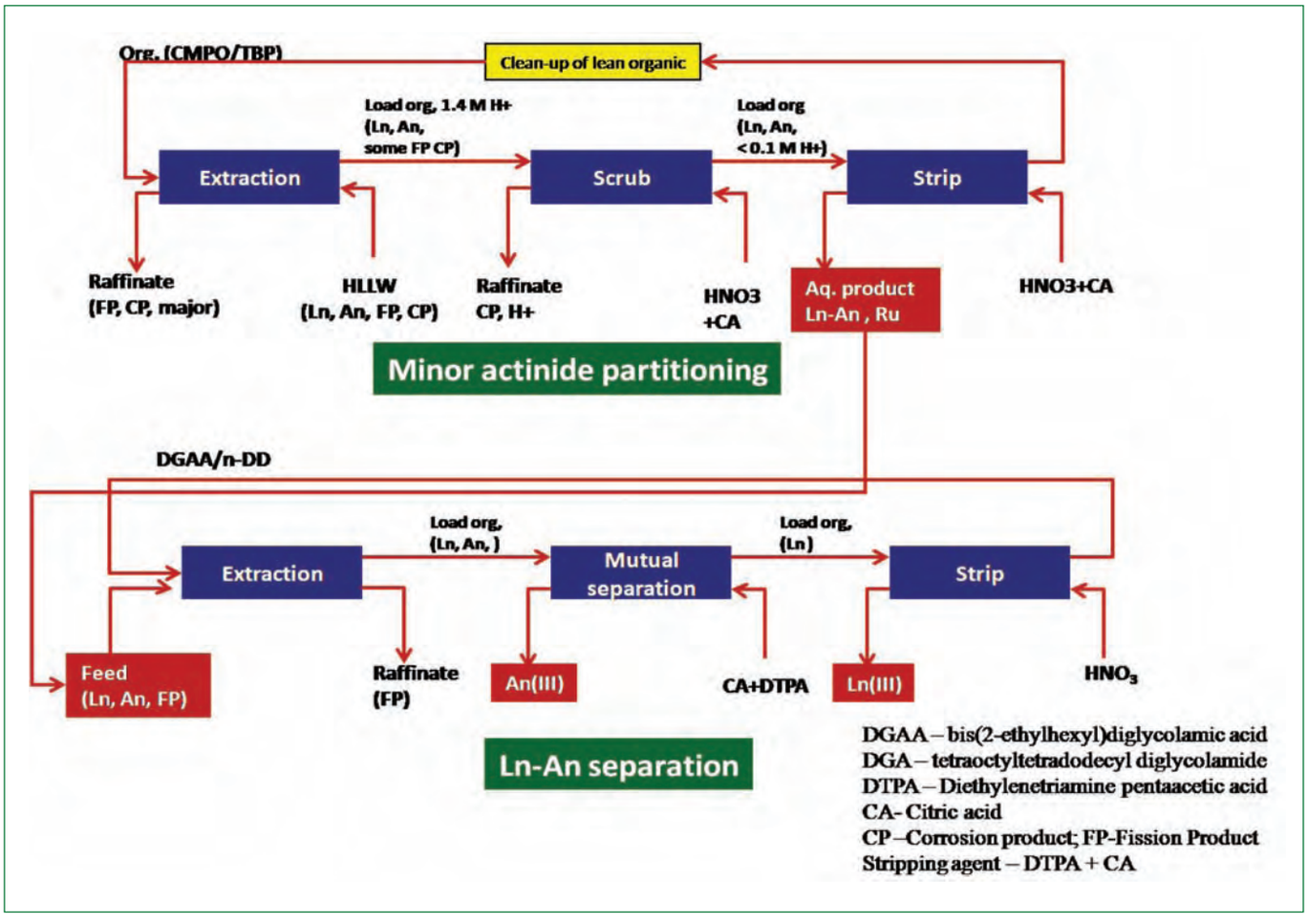


Figure 4: Proposed flow-sheet for minor actinide partitioning and lanthanide-actinide separation

actinide partitioning of high active waste (155 GWd/Te) is shown in Table 1. For batch and mixer-settler studies, the radioactive isotopes ^{154}Eu(III) (1274 keV) and ^{241}Am(III) (alpha activity) were used as lanthanide and actinide representative respectively, for assay. Initially, batch experiments were performed with the real waste. The experiments involved extraction of lanthanides and actinides in a solution of 0.1 M HDEHDGA in n-DD and stripping using 0.01 M DTPA + 0.025 M at pH 1.5. The extraction results confirmed that >99 % of An(III) and Ln(III) were extracted into organic phase and about 90 % Am(III) alone was recovered into aqueous phase within 10-12 contacts during stripping.

Based on the above results, lanthanide-actinide separation was performed using a 16-state mixer-settler installed in hot-cell (Figure 3). The feed solution was the aqueous product obtained after minor actinide partitioning was directly fed in to the mixer-settler extraction. The extraction of Am(III) and Eu(III) in 0.1 M HDEHDGA/ n-DD was quantitative in 1-2 stages. The extraction of ruthenium was negligible. The organic phase was collected and subjected to stripping using 0.01 DTPA + 0.025 M CA at pH 1.5. The analysis of organic phase showed the presence of about 95% of lanthanides (based on Eu(III) analysis) and about 25 -30% of Am(III). Similarly the analysis of aqueous phase showed the presence of about 70 - 75% Am(III) with <5% Ln(III). The results, thus, confirmed about 75% separation of lanthanides from actinides. Moreover, these results are in-line with simulated studies described above using 20 stage mixer-settler. Lower separation (~70%) achieved with actual waste could be attributed to the employment of 16-state mixer settler in hot cell, as compared to a 20-state mixer settler for simulated studies. Nevertheless, our results with simulated and real wastes demonstrate the possibility of separating actinides from lanthanides using HDEHDGA. It is worthwhile to mention here that the studies were performed and demonstrated for the first time with CHON based ligand, with the extractant soluble in a nuclear diluent, n-DD, for Ln-An separation and with real FBR waste. Based on the optimized conditions, we have proposed a flow-sheet for the minor-actinide portioning cum lanthanide-actinide separations, as shown in Figure 4.

Reported by A.S. Suneesh
Fuel Chemistry Division,
Chemistry Group

Young Researcher's FORUM

Energy and Environmental Applications of One Dimensional TiO_2 Nano-architectures Fabricated by Electrochemical Anodization

Ms Rajini P Antony did her Masters in Chemistry from Calicut University, Kerala. She joined IGCAR as a research scholar in August 2007 and pursued her Ph.D. in HBNI under the guidance of Dr. Sitaram Dash, Thin Films and Coating Section, SND, MSG and received her doctoral degree in May 2013. The title of her thesis is "synthesis, characterization and selected applications of quasi one dimensional nano-architectures of TiO_2". She has eight peer reviewed publications in international journals, four conference proceedings and presented papers in seven international conferences and received best paper award in one conference.

Innovations on new materials and material architectures embodying novel functions increase the scope of their application for assisting global sustainability. In this context, titanium dioxide (TiO_2) based materials have proven to be the most promising material because of their low cost, non-toxicity, high stability and wide range of applications in the field of energy conversion and storage, and environmental remediation. The energy based applications include photovoltaic cells, green-energy hydrogen generation by splitting of water and hydrogen storage. Whereas, environmental remediation include photocatalytic decomposition of organic pollutants in water and air, anti-bacterial, anti-viral, fungicidal and anti-soiling.

TiO_2 Photocatalysis

When the semiconductor is excited by photons of appropriate energy, electrons are excited from the valance band (VB) to the conduction band (CB) creating holes and electrons in the VB and CB, respectively. These photogenerated charge carriers migrate towards TiO_2 crystallite surface, where they reduce and oxidize adsorbed electron acceptors and donors by interfacial charge transfer. The holes participate in organic destruction either by directly oxidizing the organics before being trapped within the particle or at the particle surface or by combining with hydroxyl anions to yield hydroxyl radicals which degrade the adsorbed organic species.

The probability and rate of the charge transfer processes for electrons and holes depend upon the respective positions of conduction and valence band edges and the redox potential levels of the adsorbate species. For efficient reaction, the potential of the electron acceptor should be positioned below the CB of the semiconductor and the potential of the electron donor should be above the VB of the semiconductor. The former case applies to photocatalytic hydrogen generation and the latter applies to organic destruction. The photo generated valence band holes are powerful oxidants (+1 to +3.5 V Vs NHE depending on the semiconductor) whereas the CB electrons are strong reductants (0.5 to -1.5 V vs NHE). The schematic of the photocatalytic reaction in TiO_2 is shown in Figure 1. For applications in photovoltaics and self cleaning coatings, where nanoarchitectures of high aspect ratio, large surface area, directional electron transport properties, thin tube edges and surface roughness with long trapped air columns are expected to elevate the level of performance, vertically aligned nanotube arrays as thin films / coatings are of interest. In applications like green-energy hydrogen generation by splitting of water and photocatalytic decomposition of organic pollutants in water, suspensions of large surface area particles like nanotubes are preferred as the configuration has better light harvesting ability.

Fabrication of Self Aligned TiO_2 Nanotube Arrays by Electrochemical Anodization

It is expected that one dimensional nanostructures of TiO_2, having large surface area, high aspect ratio, vectorial electron transport and surface roughness with long trapped air columns, such as vertically aligned nanotube arrays, when used for fabricating devices such as solar cells and hydrophobic ↔ hydrophilic

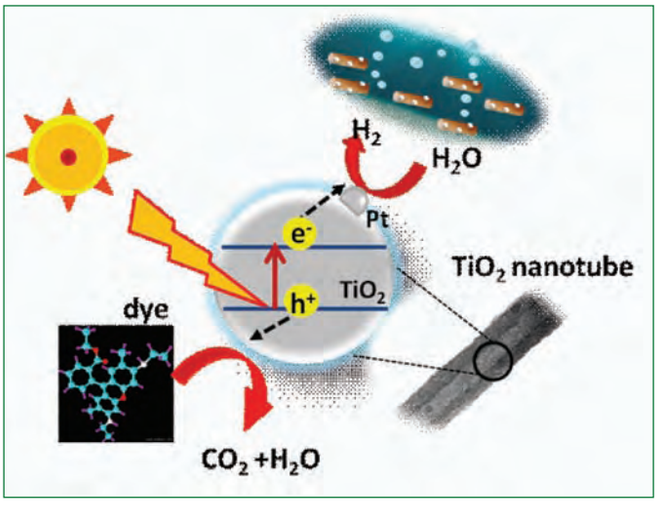


Figure 1: The schematic of the photocatalytic reaction in TiO_2

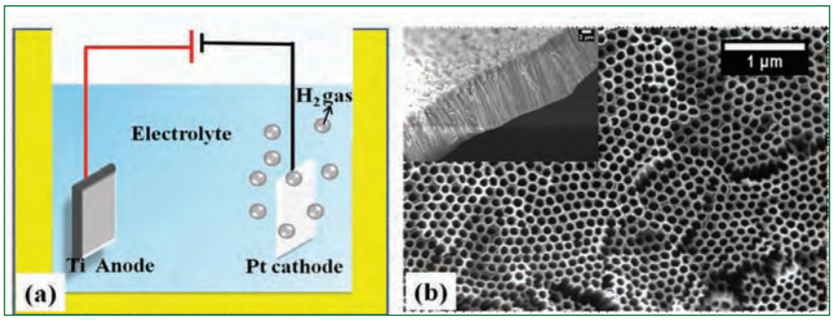


Figure 2: (a) Schematic of the electrochemical anodization set up and (b) FESEM image of the TiO_2 nanotube arrays. The inset of Figure 2b shows the cross sectional view of the organized TiO_2 nanotube arrays

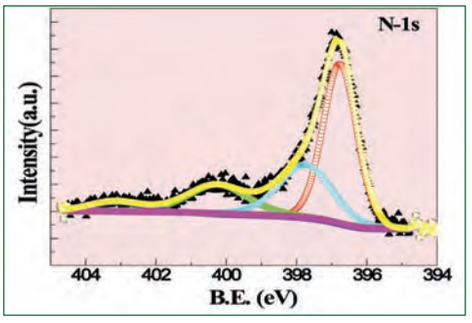


Figure 3: The high resolution N1s XPS spectra revealing substitutional N- doping

switching (self cleaning) surfaces, will enhance their overall efficiencies.

Vertically aligned TiO_2 nanotube arrays (TNTA) on foils were synthesized by potentiostatic anodization using ethylene glycol containing ammonium fluoride and water as electrolyte medium. Figures 2a and 2b show the schematic of the experimental set up and FESEM image of the fabricated TNTA, respectively. From the observed potentiostatic transients and correlation with reported results, it was confirmed that equilibrium between field assisted chemical oxidation of Ti and field assisted chemical dissolution of Ti and TiO_2 by fluoride ions played the key role in nanotube formation. From the morphological analyses of samples synthesized under various electrochemical conditions, the appropriate process parameters for attaining highly ordered, debris free TiO_2 nanotube arrays of sufficient lengths (~8 micrometers), were found to be 30 to 50 V applied potential, 2 to 3 hours of anodization time and electrolyte composition of 0.25 to 0.5 wt% of NH_4F + 2 to 3 wt% of H_2O in ethylene glycol at room temperature. The presence of different surface and subsurface defect states, such as bridging oxygen vacancies (Ti - V_0 – Ti), Ti – OH – Ti / Ti-$(OH)_2$-Ti bridge and surface terminating Ti – OH, in the nanotubes were confirmed from XPS investigations and supports the enhanced photo catalytic activity of TNTAs. The band gap of the pristine TNTA calculated from diffuse reflectance spectra was found to be ~3.27 eV.

Electrochemical Nitrogen Doping of TiO_2 Nanotube Arrays

The major drawback of TiO_2 is its large band-gap (3.0–3.2 eV), thus only 5% of the solar spectrum (corresponding to the UV region at $\lambda < 380$ nm) is absorbed. To lower the threshold energy for photoexcitation, a great deal of research has been focused on doping TiO_2 with both transition metal cations and anions. Among these, N-doping was found to be more promising. Substitution of O^{2-} ions by N^{3-} ions is more effective due to their similar size, as lattice distortion will be less and hence large numbers of recombination centres are not generated.

Synthesis of N-doped TNTA was achieved in a single step by anodizing Ti foil in 0.5 wt% NH_4F + 2.5 wt% water in ethylene glycol medium containing various wt% of urea at 40 V for two hours, followed by annealing at 400 °C. The High resolution N1s XPS spectra (Figure 3) revealed substitutional N-doping of about 3.88, 4.74 and 4.12 atom percent corresponding to formulae $TiO_{1.85}N_{0.115}$, $TiO_{1.813}N_{0.14}$ and $TiO_{1.84}N_{0.121}$, and the band gap values are 3.22, 2.75 and 2.77 eV respectively. The optical band gap was found to shift to lower values with N-doping and introduction of inter-band state could be discerned from the absorption spectrum.

Photoinduced Near Super Hydrophobic to Superhydrophilic Transition

The surfaces that are able to switch between superhydrophobic and superhydrophilic ones are of importance because of their potential application to create smart membranes / self cleaning surfaces. The near superhydrophobic to superhydrophilic conversion kinetics of pristine and N-doped TNTA were investigated under UV (1.4 $mW/cm^{2)}$ as well as sun light (44 mW/cm^2). The water contact angles, before irradiation, obtained for vertically aligned anatase pristine and N-doped TNTAs are 140 and 125°, respectively. The hydrophobic films underwent transition to super hydrophilic state under UV light and reversed to hydrophobic state when kept in dark. Under sun light irradiation, complete superhydrophilicity is observed for N-doped TNTA and this is achieved within 90 minutes. The recovery, when kept under dark could be attained within two and half days and the effects are revealed from the switching pattern (Figures 4a and 4b). Since no single mechanism could explain all the observed experimental results, a combination of mechanisms (photocatalytic decomposition of adsorbed organics and photo induced surface reconstruction) has been proposed. The XPS investigations revealed that, among the two processes photocatalytic decomposition of adsorbed organics and its adsorption under dark plays the dominant role in the switching

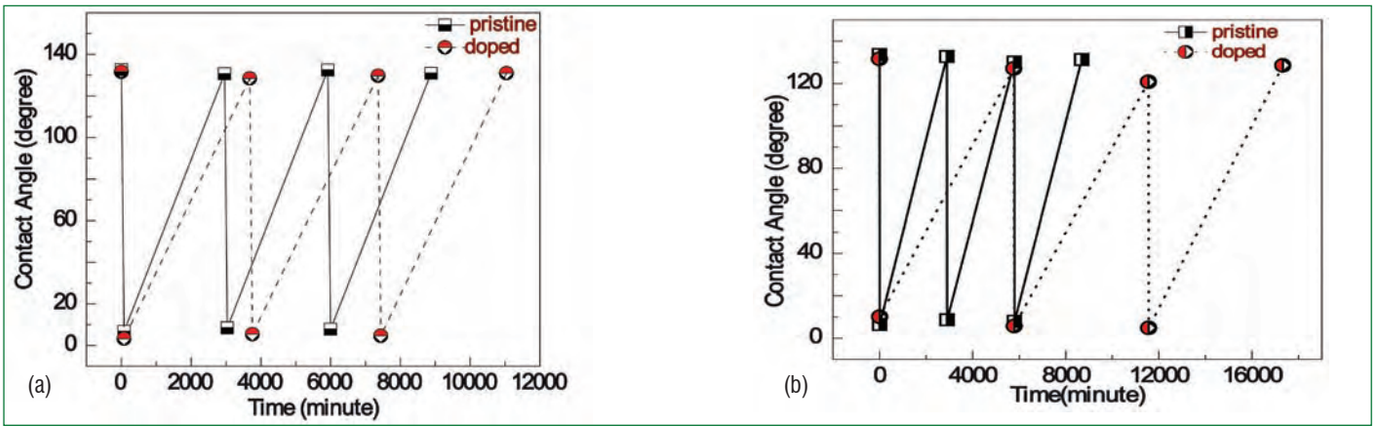


Figure 4: Near super hydrophobic ↔ superhydrophilic switching in pristine and N-doped TNTA (a) under visible light (b) under UV light

process. The observed near wetting ↔ dewetting switching behaviour indicate the potential of TNTA coatings for application as smart surfaces.

Fabrication of TiO_2 Nanotube Powder by Rapid Break Down Anodization

For applications such as photocatalytic hydrogen generation and organic pollutant destruction, TiO_2 nanotubes in the powder form are more efficient, as these can be suspended in the media thereby facilitating better light harvesting. TiO_2 nanotube powders were synthesized by anodizing Ti foils in perchloric acid media. The FESEM and TEM (Figures 5a and 5b) revealed tubes of uniform diameter (15 to 18 nm) and wall thickness (~5 nm). The SAED pattern (inset of Figure 5b) and XRD analysis revealed that the as prepared nanotubes to be of anatase phase. The band gap values varied from 2.95 to 3.07 eV indicating near UV and visible light absorption capabilities. The samples had surface area as high as 155 m^2/g. FTIR and PL spectroscopic studies revealed presence of defect states which is crucial for the photo catalytic applications.

The C & N co-doped nanotube powders were tried by anodizing Ti foils in perchloric acid media containing urea as the nitrogen source. XPS analysis revealed interstitial N-doping and substitutional C-doping for TiO_2 nanotube powders. Similar to the pristine TiO_2 nanotube powders, the C and N- co-doped samples were of anatase phase and exhibited high specific surface area (124 m^2/g). The FESEM and TEM analysis revealed destruction of tubular architecture upon doping.

Photocatalytic Hydrogen Generation and Dye Degradation Kinetics of TiO_2 Nanotube Powders

The photocatalytic efficiency of pristine as well as N and C co-doped TiO_2 nanotube were studied by investigating their green energy hydrogen generation and organic pollutant destruction efficiency. Since the Fermi levels of the noble metals (Pt, Au and Pd) are lower than the TiO_2 conduction band, when loaded on to TiO_2, the photo excited TiO_2 electrons move to the noble metal Fermi levels leaving the holes in the valence band, reducing the electron – hole recombination and thereby enhancing the photocatalytic efficiency. Among these noble metals Pt is reported to be the most efficient. Hence, TiO_2 nanotube powders were loaded with Pt at different weight percentages (1 to 10 wt%) by chemical reduction technique using sodium borohydride. The decrease in PL intensity

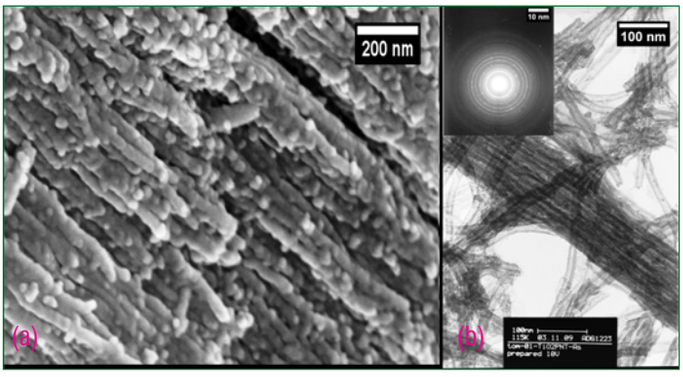


Figure 5: (a) FESEM and (b) TEM image of the TiO_2 nanotube powders. Inset of figure 7b shows SAED pattern revealing anatase phase crystallinity

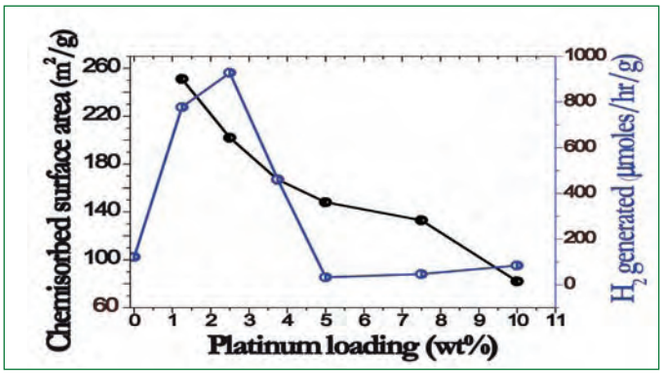


Figure 6: The variation of chemisorption surface area and hydrogen generation efficiencies with different weight percent of Pt loading on TiO_2

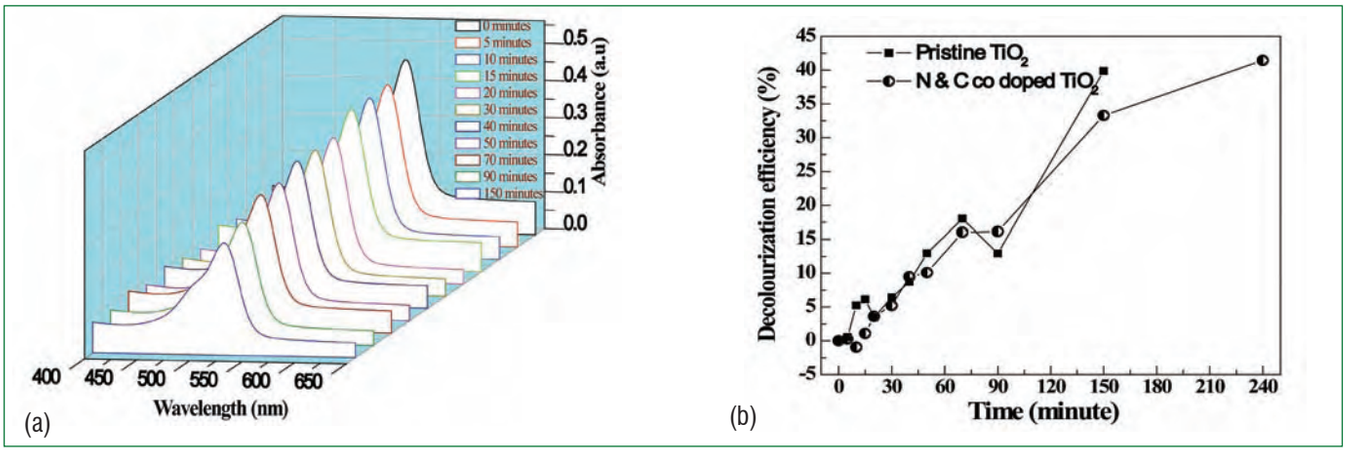


Figure 7: (a) UV – Visible absorption spectra showing the decrease in dye concentration with sunlight irradiation time (b) the dye destruction efficiencies of pristine and doped samples under sunlight

indicate reduction in electron hole recombination on Pt loading. The chemisorption surface area of Pt was measured by temperature programmed desorption reduction oxidation technique and was found to be high at low Pt loadings (1 to 2.5wt% of Pt). The H_2 gas generated from 1:3 water – ethanol reaction mixture was measured using a polymer electrolyte membrane based H_2 sensor. Hydrogen generation efficiency is found to decrease with increase in Pt loading. Figure 6 shows the variation of chemisorption surface area and hydrogen generation efficiencies with Pt loading varying from 1.25 to 10 wt%. The highest H_2 generation rate, under near UV light (~380 nm and 120 W), was observed at 1.25 and 2.5 wt% Pt loadings and are 777.3 and 927.9 μ moles of H_2 / h for 1 g of Pt-TiO_2 catalyst, respectively. For an incident light of 254 nm wave length (64 W) and with 1.25 wt% Pt loading, the hydrogen generation rate obtained was 0.030 moles / hour for 1 g of Pt/TiO_2. The turn over frequencies (TOF) for the catalytic reaction calculated using the equation:

TOF = rate of H_2 generation (mols s^{-1}) / moles of surface Pt atoms present are

3.5×10^{-3}, 3.5×10^{-3}, 1.1×10^{-3}, , 6.6×10^{-5}, 8.0×10^{-5} and 15.27×10^{-5} s^{-1}, for 1.25, 2.5, 3.75, 5, 7.5 and 10 wt% Pt loadings respectively. The TOF value for H_2 generation from 1.25 wt% Pt loaded sample suspensions under $\lambda = 254$ nm UV light was found to be 13.69 s^{-1}. Taking into consideration the low amount of Pt loading and the low power of UV sources used, the hydrogen generation rates obtained are the highest among the reported values.

The dye degradation efficiencies of pristine and C and N- co-doped TiO_2 nanotube powders were investigated, using Rhodamine 6 G dye as a model pollutant, under sunlight of 44 mW/cm^2 intensity. The change in dye concentration with irradiation time was measured using UV-visible absorption spectroscopy (Figure 7a). It is observed that the degradation rate follows apparently first order kinetics and the calculated rate constants are found to be 4.99×10^{-5} s^{-1} and 3.99×10^{-5} s^{-1} for pristine and doped samples, respectively. The dye destruction efficiencies of pristine and doped samples are around ~ 40% in 150 minutes (Figure 7b). Even though a slight decrease in the band gap on doping was observed, the photocatalytic efficiency of the doped samples is low. This can be attributed to generation of charge carrier recombination centres upon doping.

One dimensional TiO_2 nano-architectures in self organized arrays as well as in powder form were synthesized by anodization technique. Tuning of the morphology and aspect ratio of the TiO_2 nanotubes were achieved by varying the electrochemical parameters such as applied potential, anodization time and electrolyte composition. Fabrication of visible light active N-doped TiO_2 nanotube arrays and N & C co-doped TiO_2 nanotube powders were done by employing urea as the nitrogen precursor in the electrolytic medium. Photocatalytic efficiency of high surface area anatase phase, pristine and N- doped TiO_2 nanotube arrays and powders were elucidated by studying the surface wetting, photocatalytic hydrogen generation by water splitting and dye degradation kinetics. The enhanced photocatalytic efficiency of the one dimensional TiO_2 nanotubes fabricated by electrochemical anodization make them high performance candidate material for energy and environmental remediation.

Reported by Rajini P Antony
Surface and Nanoscience Division
Materials Science Group

Conference and Meeting Highlights

Theme Meeting on
STAINLESS STEELS FOR POWER SECTOR (SSPS 2013)
October 20–21, 2013

Inaugural session of theme meeting on Stainless Steels for Power Sector - 2013

The Theme Meeting on "Stainless Steels for Power Sector (SSPS 2013)" was jointly organized by IGCAR, IIM, Kalpakkam Chapter, Society for Failure Analysis and IIW, Chennai Branch.

The objective of the theme meeting was to provide a forum for the designers, practicing engineers, R&D and plant personnel, to interact and discuss the issues, and act as a forum to generate novel ideas and solutions to the application of stainless steels for power sector. The scope of the theme meeting involved manufacturing aspects of conventional stainless steels, high performance stainless steels, design of new alloys, surface engineering and treatment, fabrication and welding including codes and standards, thermo-mechanical processing, advanced welding and testing, coatings and hardfacing, nondestructive evaluation - special NDT techniques, modern testing and advanced protection measures, online corrosion monitoring, New alloys and manufacturing technologies, case studies and recommendations, life prediction and modeling in Thermal and Nuclear Power Plants.

Dr. P. R. Vasudeva Rao, Director, IGCAR welcomed the gathering of the theme meeting and Prof. P. Rama Rao, Chairman, ARCI and Chairman, BRNS, delivered the inaugural address. In his inaugural address Prof. Rama Rao admired the way stainless steels have been developed and utilized for a variety of industrial applications and appreciated the progress made towards the development, fabrication and corrosion control of stainless steels. Dr. T. Jayakumar, Director, MMG outlined the scope and programme of the event and the genesis of the theme meeting. In the first session Shri S.C. Chetal, former Director of our Centre detailed applications of stainless steels for FBR, Dr. Prabhat Kumar, CMD, BHAVINI elaborated the success of stainless steel equipment fabrication for PFBR. Shri M. Narayana Rao, CMD, MIDHANI talked on development and manufacture of stainless steel for nuclear and thermal power plants, and Shri Johan Hernblom from Sandvik, Sweden explained material aspects of advanced ultra super critical boilers for clean energy. In the second session Shri S. Sisodia and Shri Sandeep Maheswari from Salem Steel Plant and Jindal Stainless Steel respectively described the versatility of stainless steel especially in power plant applications. Dr. Krishnan Balasubramaniam from IIT-M spoke on a specialized topic, NDE of stainless steel components using ultrasonic techniques. In the third session experts from BARC, Shri K.K. Vaze and Dr. V. Kain described the applications of stainless steel in advanced heavy water reactor and corrosion issues for stainless steel in light water reactors, respectively. Shri R. Easwaran detailed the BHEL experience in manufacturing stainless steels for steam generating equipment of power plants.

In the fourth technical session, Shri D. Pramanik of NFC spoke on new manufacturing processes for development of seamless stainless steel tubes for power sector applications, and Dr. P. Chellapandi, Director, RDG of IGCAR presented on stainless steels for FBR-I and FBR-II. Dr. T. Jayakumar, Director, MMG covered the developments of advanced stainless steels for sodium cooled fast reactors. In the fifth technical session, in his talk Prof. David J. Smith, Prof. Alan Cocks, Prof. John Bouchard from Universities in UK covered certain aspects in mechanical metallurgy of stainless steels, like effect of repair welds on low temperature fracture, creep deformation, damage development, crack growth, residual stress driven creep etc. Dr. A. K. Bhaduri, AD, MTDG talked on development of 304HCu stainless steel for the Indian advanced ultra super-critical thermal power plants. In the sixth and final session, Dr. G. Balachandran explained development of creep resistant stainless steels for power plants and Dr. M. D. Mathew and Dr. U. Kamachi Mudali of IGCAR, talked about evolution of Type 316 SS as a structural material for sodium cooled fast reactors and localized corrosion behaviour of nitrogen alloyed stainless steels, respectively.

About one hundred delegates participated in this theme meeting from different organizations like NFC, AERB, IPR, NPCIL and IGCAR along with institutes and industries like CECRI, IIT-M, Bharat Forge, MIDHANI, Jindal Stainless Steel, SAIL, Salem and Hyderabad, BHEL, Trichy, and Sandvik Asia, Pune. The meeting provided an opportunity for experts and all the stake holders to discuss and share their views.

Reported by U. Kamachi Mudali, Convener, SSPS - 2013

9th Biennial National Conference on Recent Advances in Information Technology (READIT) December 18-19, 2013

Dr. M. Sai Baba, Convener, READIT & AD, RMG, Dr. P.R. Vasudeva Rao, Distinguished Scientist & Director, IGCAR, Dr. J.K. Suresh, Former Vice President, Infosys, Shri S.A.V. Satya Murty, Director, EIRSG and Shri E. Soundararajan, SIRD during the release of souvenir at the inaugural function of READIT-2013

The 9th Biennial National Conference on Recent Advances in Information Technology (READIT) was organized by SIRD, IGCAR in association with the Kalpakkam Chapter of Madras Library Association (MALA) during December 18-19, 2013. The theme of the Conference was "Towards Semantic Digital Library Infrastructure". More than two hundred delegates including information technology professionals, librarians, students and academicians attended the conference.

The conference included invited talks by eminent experts, oral/poster presentations by research scholars/participants. The conference was preceded by a one day tutorial session on the theme "Tools for Creating Content Portals" on December 17, 2013. The conference was inaugurated on December 18, 2013. The function was presided over by Dr. P.R. Vasudeva Rao, Distinguished Scientist & Director, IGCAR. Shri S.A.V. Satya Murty, Director, EIRSG, IGCAR & Chairman, Library and Information Services Committee, who delivered the welcome address. Dr. M. Sai Baba, Convener, READIT, AD, RMG & Head, SIRD briefed about the activities and READIT conference. Dr. P. R. Vasudeva Rao in his presidential address emphasized the importance of libraries in providing access to the semantic information. Dr. J.K Suresh, former Vice President, Infosys & Consultant, Knowledge Management, Bengaluru delivered the inaugural address. Dr. J.K. Suresh highlighted the methods of creating knowledge in his address. Dr. J.K. Sureshand also released the souvenir and Dr. P.R. Vasudeva Rao inaugurated the exhibition. Shri E. Soundararajan, Organizing Secretary READIT, SIRD proposed the vote of thanks.

Intensive technical discussions on various aspects of virtualized digital library infrastructure, cloud computing techniques, e-books and enabling architecture, semantic metadata creation and retrieval, knowledge dissemination techniques were presented during the conference. There was also a separate poster session for the contributed papers.

An exhibition was organized as a part of the conference in which latest IT gadgets, standards and books were displayed. This conference facilitated good interaction among the young researchers/students, professionals and eminent speakers in the area of semantic technologies. During the valedictory function, Dr. M. Sai Baba summed up the overall deliberations in the conference.

Reported by M.Sai Baba
Convener, READIT-2013

Dr. P.R. Vasudeva Rao, Distinguished Scientist & Director, IGCAR inaugurating the exhibition of READIT-2013

Visit of Dignitaries

Dr. G. Venkataraman, Director (Retd.) ANURAG, DRDO & Former Vice-Chancellor, Sri Sathya Sai Institute of Higher Learning delivering the IGC Colloquium

IGC Colloquium on "What Does One do, when the Job is Over ?" was delivered by Dr. G. Venkataraman, Director (Retd.) ANURAG, DRDO & Former Vice- Chancellor, Sri Sathya Sai Institute of Higher Learning during his visit to the Centre on November 13, 2013. He also visited various facilities in the Centre.

Dr. Praveen Chaddah, Outstanding Scientist, RRCAT, Indore, delivered the IGC Colloquium on "Liquefaction of Helium and the Opening of Frontiers in Science & Technology" during his visit to the Centre on December 02, 2013.

Dr. Praveen Chaddah, Outstanding Scientist, RRCAT, Indore delivering the IGC Colloquium

Prof. K. Ramnarayan, Vice Chancellor, Manipal University delivering the IGC Colloquium

Prof. K. Ramnarayan, Vice Chancellor, Manipal University during his visit to the Centre on December 23, 2013 delivered the IGC Colloquium on "The Vanishing art of Lecturing".

Visit of Bharat Ratna Prof. C.N.R. Rao to IGCAR
December 28-30, 2013

Prof. C.N.R. Rao with Dr. P. R. Vasudeva Rao, Director, IGCAR, Dr. C.S. Sundar, Director, MSG and Dr. K. Anathasivan, CG during his visit to the Chemistry Group

Bharat Ratna Prof. C.N.R. Rao, F.R.S., National Research Professor, Honorary President & Linus Pauling Research Professor, Jawaharlal Nehru Centre for Advanced Scientific Research visited IGCAR during December 28-30, 2013. He met the senior colleagues of the Centre and discussed about various programmes in progress. He visited the Magnetocardiography/magnetoencephalography facility at Materials Science Group, spot technique facility for measurement of solidus-liquidus temperature of fuels & sensor laboratory in Chemistry Group, sodium fire and safety related facilities in Reactor Design Group, components testing facilities in Fast Reactor Technology Group and construction site of PFBR at BHAVINI. As a part of his visit, Prof. C.N.R. Rao interacted with Young Officers of the Centre and shared his experiences.

Prof. C.N.R. Rao, delivered the IGC Colloquium on "Celebration of Science" during his visit to the Centre on December 30, 2013. His lecture highlighted the contributions made by the eminent scientists in the field of Chemistry in the past tracing back to history and he also introduced many of them to the audience through his collection of rare historical photographs. Apart from this he highlighted the significance of year 2011 and 2012 especially with reference to Chemistry and their impact on further progress. The year 2011 marked the centenary of discovery of atomic structure by Rutherford, discovery of superconductivity by Kamerlingh Onnes and second Nobel Prize of Marie Curie, and the year 2012 marked the Centenary of the discovery of X-ray Crystallography. It is well known that Prof. Rao is an excellent orator, the lecture was very informative at the same time thought provoking.

Prof C.N.R. Rao delivering the IGC Colloquium

Awards & Honours

Dr. P. Chellapandi was awarded the "National Design Award - 2013" by National Design and Research Forum, Institution of Engineers (India) for his outstanding contributions on December 20, 2013 during the 28th Indian Engineering Congress at Chennai.

Dr. S. Venugopal has been awarded of the D.Sc. Degree by the University of Madras for his thesis entitled "Contribution to the Optimization of Parameters for Mechanical Working and Controlling the Development of Micro Structure during Hot Working of Metallic Materials".

Dr. C.S. Sundar has been elected as APAM Academician by Asia Pacific Academy of Materials.

Dr. D. Sornadurai has received the "Recognition Award -2013" from International Centre for Diffraction Data (ICDD), USA in recognition of his outstanding contributions towards solving crystal structures of many new materials and publishing them in standard powder diffraction files of PCPDF-4+2013 database.

Best Paper/Poster Award

Effect of Water Gap among Adjustable Reflector Blocks on k-eff of KAMINI Reactor
Smt. E. Radha, Shri V. Sathiamoorthy, Dr. R.S. Keshavamurthy and Dr. C.P. Reddy from ROMG
DAE-BRNS National Symposium on Advances in Reactor Physics (ARP 2013): Simulation Techniques and Analysis Methodologies,
October 23-25, 2013, BARC Training School Hostel, Anushakthi Nagar, Mumbai
Best Poster Award

Design and Development of FPGA based VMEbus Interface Controller(VIC) for Computer based I&C systems of Fast Reactors
Shri Raghavan Komanduri and Shri D. Thirugnanamurthy from EIRSG
The Annual IEEE India Conference on Impact of Engineering on Global Sustainability (INDICON-2013), December 13-15, 2013, Victor Menezes Convention Centre (VMCC), IIT Bombay, Mumbai
Best Paper Award

Evolution and Defect Analysis of Graphene Nanosheets grown by ECR-CVD
Ms. Subrata Ghosh, Dr. K. Ganesan, Shri Shyamal R. Polaki, Dr. T.R. Ravindran, Shri Nanda Gopala Krishna, Shri M. Kamruddin and Dr. A. K. Tyagi from MSG, International Conference in Asia - 2013 (IUMRS ICA 2013)
Organised by International Union of Materials Research Society and Materials Research Society of India
December 16-20, 2013, Indian Institute of Science, Bengaluru
Best Poster Presentation Award

Wireless Sensor Network for Temperature and Humidity Monitoring in a Nuclear Facility
Ms. D. Baghyalakshmi, Shri T. Chandran, Ms. Jemimah Ebenezer and Shri S.A.V. Satya Murty from EIRSG
International Conference on Advanced Computing (ICoAC-13)
December 18-20, 2013, Anna University, Chennai
Best Paper Award (the Paper has been accepted for publication in the IEEE Xplore Digital Library and available in IEEE Explore)

Intelligent Web Mining Techniques
Ms. Molly Mehra, Smt. S. Rajeswari, Shri K.K. Kuriakose and Shri S.A.V. Satya Murty
Conference on Recent Advances in Information Technology (READIT), December 17-19, 2013, IGCAR
Best Poster Presentation Award

Development of Knowledge Management Portal for Research Scholars
Ms. J. Jasmine Smila, Smt. K. Saipriya, Dr. Vidya Sundararajan and Dr. M. Sai Baba
Conference on Recent Advances in Information Technology (READIT), December 17-19, 2013, IGCAR
Best Poster Presentation Award

Ontology Based Wiki System for Fast Reactor Domain
Shri L. Nandha Gopan, Shri E. Soundararajan and Dr. M. Sai Baba
Conference on Recent Advances in Information Technology (READIT), December 17-19, 2013, IGCAR
Best Oral Presentation Award

DAE Awards

Department of Atomic Energy has instituted annual awards for excellence in Science, Engineering and Technology in order to identify best performers in the area of Research, Technology Development and Engineering in the constituent units (other than Public Sector Undertakings and Aided Institutions). The Young Applied Scientist, Young Engineer, Young Technologist, Homi Bhabha Science and Technology Award and Scientific and Technical Excellence Award fall under this category. Group Achievement awards for recognition of major achievements by groups have also been instituted. Life-time Achievement Award is awarded to one who has made significant impact on the DAE's programmes. They are the icons for young scientists and engineers to emulate. The awards consist of a memento, citation and cash prize.

The recipients of the Awards from IGCAR for the year 2012 are:

Scientific and Technical Excellence Award : Shri G. Padmakumar, FRTG
Shri Sanjay Kumar Das, RDG

Young Applied Scientist/Technologist Award : Shri Shiv Prakash Ruhela, FRTG
Shri Prashant Sharma, FRTG

Young Engineer Award : Shri Sanjay Kumar Pandey, RDG
Ms. Diptimayee Samantaray, MMG
Shri J. Kothandaraman, RpG

Meritorious Technical Support Award : Shri M. Arumugam, ROMG
Shri S. Selvam, ESG
Shri R. Devarajulu, MMG
Shri C. Ambujakshan Nair, FRTG
Shri M. Chandrasekaran, ROMG

Meritorious Service Award : Smt. Saroja Gopal, presently at DAE, Mumbai
Smt. S. Viji, Director's Office

Group Achievement Awards:

Design, Development and Manufacture of Titanium Dissolver for Fast Reactor Fuel Reprocessing
Shri B.M. Ananda Rao, RpG, Group Leader
Shri M.V. Kuppusamy, Shri Navtesh Bajpai, Shri Saju T Abraham, Shri D Kuppusamy, Shri C. B. Rajeev, Shri G. Kaliamoorthy and Dr. B. Venkatraman from EIRSG, Shri T. Karthikeyan, Dr. R. Mythili, Dr. Arup Dasgupta, Dr. Saroja Saibaba, Dr. M. Vijayalakshmi, Shri Harish Chandra Dey, Dr. Arun Kumar Bhaduri, Shri T. Nanda Kumar and Dr. U. Kamachi Mudali from MMG, Shri Sanatana Maharana, Shri S. Solomon Nesakumar, Shri S.K. Gupta, Shri T. Dinesh, Shri V. Muralikrishnan, Shri H. Humayoun and Shri A. Ravisankar from RpG

Design, Manufacture and Deployment of Passive Neutron based Alpha Waste Drum Assay System
Shri R. Amudhu Ramesh Kumar, RpG, Group Leader
Shri C.R. Venkatasubaramani from CG, Smt. R. Akila from EIRSG, Shri M. Geo Mathews, Shri E. Balu, Shri A. Palanivel and

Shri P. Sivakumar, Shri Padi Srinivas Reddy, Shri K.K. Shimjith, Shri R. Anbarasan, Shri V. Anandha Narayanan, Shri Akhilesh K Nair, Shri K. Stanley, Shri Saptarsi Chaterjee, Ms. S.Usha, Shri Ch.U. Bhanu Prasad, Smt. S. Poongodi, Shri N.T. Bineesh. Smt. P. Dhanalakshmi, Ms. S. Eswari and Smt. V. Ramya from RpG

Integrated Top Shield Test Facility and Validation of Thermal Design of PFBR Top Shield

Shri Sriramachandra Aithal, RDG, Group Leader

Shri N. Vijayan Varier, Shri Vimal Kumar and Shri Makrand B Rajhans from TCQCD, Shri P. Jagannathan from EIRSG, Shri C. Sivathanu Pillai, Shri K. Velusamy, Shri V. Venkatachalapathy, Shri Vasa Trinadh Gopi, Shri G. Ramnathan and Shri P. Palani from ESG, Shri S. K. Samantaray, Shri P. Ramamoorthy and Shri T. Kumaran from FRFCF, Shri V. Rajan Babu, Shri P. Puthiyavinayagam, Shri V. Balasubramaniyan, Shri K. Krishnaprasad, Smt. R. Vijayashree, Shri S. Raghupathy, Dr. K. Velusamy, Shri R. Gajapathy, Shri U. Parthasarathy, Shri B. Madhavan, Shri S. Saravanan, Shri M. Sakthivel, Shri Govind Kumar Mishra, Shri V. Pradeesh, Shri E. Balasundaram, Shri C. Raghavendran, Smt. P. Swetha, Shri G. Venkataiah, Shri S.K. Rajesh, Shri M. Babu Rao, Shri R. Manu, Shri S. Ramesh, Shri A. Sivakumar, Shri V. Devaraj and Shri P. Raja from RDG

Design, Construction, Commissioning and Licensing of Interim Fuel Storage Facility

Shri P. V. Kumar, then FRFCF & ESG(C), Group Leader

Shri G. Srinivasan, Ms. S. Usha, Shri S. Varatharajan, Shri P.R. Swaminathan, Shri M. Elango, Shri R.V. Ramesh, Shri P. Ravi, Shri S. Baskaran, Shri S. Domesan, Shri A. Thandavamoorthy, Shri M. Uthaman, Smt. Liji Jacob, Shri N. Gopalakrishnan, Shri A.P. Abdul Mustak, Ms. S. Meena, Shri V. J. Ramalingeswara Rao, Smt. V. Jayachitra, Shri K. G. Subramanian, Shri N. Sampath Kumar, Shri S. Sarangarajan, Shri E. Ramesh, Shri R. Shanmugavel, Shri Kalyana Rao Kuchipudi, Shri D. Devaraj, Shri P. Ragothkumar and Shri S. Rama Rao from ROMG, Smt. Thilakavathy, Smt. V. Gandhimathi, Shri Harikumar, Shri R.J. Paul Surendranath, Shri Nadarajan and Shri K Vasudevan from ESG, Dr. M.T. Jose, Dr. N Suryamurthy, Shri R. Sarangapani and Shri P. Arumugam from EIRSG

The award is also shared by Shri A.C. Wali, Shri A.V.G, Reddy and Shri B. Ravinder from FRF, NFC

Performance Testing of Primary Ramp and Primary Tilting Mechanism of the Inclined Fuel Transfer Machine of PFBR

Shri B.K. Sreedhar, FRTG, Group Leader

Shri N. Murugesan from CG, Shri G. Ramesh, Shri Krishna Tripathi, Shri P. Rajasekar, Shri M.P. Prabhakar, Shri G. Vijyaraghavan and Smt Alka Kumari from EIRSG, Shri G. Kempulraj, Shri B.S. Ramesh Babu, Shri V. Praveen Kumar, Shri M. Krishnamoorthy, Shri V. Rajendran, Shri N. Chockalingam, Shri K. Narayanan, Shri C. Muthuswamy, Shri K.M. Natarajan, Shri R. Raj Kumar Bharathi, Shri S. Manimaran, Shri R. Manikandan, Shri Mohamed Shijas. B, Shri J. Abilash, Shri R. Murugapandian, Shri M. Pradeesh and Shri M. Tulasi from ESG, Shri B.K. Nashine, Shri G. Padmakumar, Shri B. Babu, Shri G. Vijayakumar, Shri S. Chandramouli, Shri V. Ramakrishnan, Shri P. Vijaya Mohana Rao, Shri C. Asokane, Shri S.C.S.P. Kumar Krovvidi, Shri Nilayendra Chakraborty, Shri S. Ignatius Sunder Raj, Shri P. Madan Kumar, Shri R. Rajendra Prasad, Shri A. Ashok Kumar, Shri K. Jayagopi, Shri Rakesh Kumar Mourya, Shri J. Saravanan, Shri T.V. Maran, Shri M. Anbuchelian, Shri Shiv Prakash Ruhela, Shri Y.V. Nagaraja Bhat, Shri R. Nirmal Kumar, Shri S. Krishnakumar, Shri D. Laxman, Shri S. Sureshkumar, Shri Gautam Kumar Pandey, Shri D. Muralidhar, Shri S. Ravishankar, Shri S. Alexander Xavier, Shri Parmanand Kumar, Shri N. Venkatesan, Shri K. Mohanraj, Shri C. Rajappan, Shri P.C.V. Murugan, Shri N. Sreenivas, Shri L. Egambaram, Shri R. Iyyappan, Shri N. Mohan, Shri G. Anandan, Shri A. Sudarsana Rao, Shri A. Kolanjiappan, Shri R. Ramalingam, Shri R. Shanmugam, Shri C. Adikesavan, Shri K. Karunakaran, Shri R. Krishnamurthy, Shri M. Sambamurthi, Shri P. Bakthavatchalam, Shri C. Ambujakshan Nair, Shri A.T. Loganathan, Shri A. Govindarajan, Shri M.T. Janakiraman, Shri P. Ganesan, Shri A. Kulanthai, Shri S. Shanmugam, Shri D. Kuppuswami, Shri P. Sonai, Shri P.R. Ashokkumar, Shri P. Varadan, Shri N. Thulasi, Shri K. Arumugam, Shri A. Anthuvan Clement, Shri V. Gunasekaran, Shri M. Kathiravan, Shri M. Karthikeyan, Shri Shaik Rafee, Shri S. Rajkamal Singh, Shri K. Srinivasa Rao, Shri N. Mariappan, Shri K.H. Anub, Shri H. Rafiq Basha, Shri K. Ganesh, Shri Ashish Tiwari, Shri L. Mohanasundaram, Shri L. Muthu, Shri P. Pothi, Shri P. Lakshmayya, Shri K. Palani, Smt. J.I. Sylvia, Smt. S. Nagajothi, Smt. Shanthi Rajendran, Smt. M. Chandra and Shri M. Mohana FRTG, Dr. U. Kamachi Mudali and Shri T. Nandakumar from MMG, Dr. P. Chellapandi, Dr. K. Velusamy, Shri S. Raghupathy, Shri K. Madhusoodanan, Shri Jose Varghese, Shri A. Venkatesan, Shri C.S. Surendran, Shri M. Rajendrakumar, Shri N. Subramanian, Shri Juby Abraham, Shri Ram Kumar Maity, Shri P. Lenin, Shri E. Balasundaram from RDG

The award is also shared by Dr. S. Roy, Shri P.K. Limaye, Shri M. Dev, Shri Jit Pal Singh, Shri Somesh Rai and Dr. R.J. Patel from RD&DG, BARC

Design, Development, Verification & Validation of Hardware & Computer based Systems for Instrumentation & Control of PFBR

Shri S.A.V.Satya Murty, EIRSG, Group Leader

Shri N. Murali, Shri R. Jehadeesan, Shri M.L. Jayalal, Shri D. Thirugnana Murthy, Shri N. Sridhar, Shri K. Palanisami, Smt. T. Sridevi, Shri G. Venkat Kishore, Smt. L. Srivani, Shri Md. Najam Anwer, Shri Manoj Kumar Misra, Smt. K. Kameswari, Smt. T. Suguna, Shri M.A. Sanjith, Shri N. Satheesh, Smt. Saritha P. Menon, Shri T. Gokulakrishnan, Shri J. Selva Solomon, Shri A. Nageswaran, Smt. E.M.T. Sirisha, Shri Rajesh Vadarevu, Shri Alok Kumar Gupta, Shri Raghavan Komanduri, Shri R. Kanagarajan, Shri P. Shanmuganathi, Shri G. Prabhakara Rao, Shri P. Sahoo, Shri A. Shanmugam, Shri R. Ramakrishnan, Smt. P. Parimalam, Shri R.P. Behera, Shri M. Manimaran, Shri M. Kasinathan, Shri Mahesh Kumar Patankar, Shri M.S. Chandramouli Sharma, Smt. N. Malathi, Shri R. Ananthanarayanan, Shri M.P. Rajiniganth, Shri K. Praveen, Shri Aditya Gour, Shri A. Santhana Raj, Shri Anindhya Bhattacharya, Shri P. Manoj, Shri A.D. Arun and Smt. V. Lalitha from EIRSG, Shri B. Sasidhar Rao from FRFCF, Shri K. Madhusoodanan, Shri S. Lekshminarayanaswamy, Shri A. Venkatesan, Shri C.P. Nagaraj, Shri Tanmay Vasal, Shri M. Sivaramakrishna, Shri M. Sakthivel, Shri R. Dheenadhayalan, Shri N. Subramanian, Shri Chandrakant Upadhyay, Shri Govind Kumar Mishra, Shri Ankit Kumar, Shri R. Varuna, Ms T. Somavathi, Shri V. Pradeesh, Ms. A. Nisha, Shri E. Balasundaram and Shri N. Anandakumar from RDG, Shri V.J. Ramalingeswara Rao, Smt. K. Vinolia and Smt. Gowri Lakshmanan from ROMG.

The award is also shared by Dr. K.P. Sarkar, Smt. Geetha Santhakumar, Shri Ramesh B Adelli, Shri Anup Suryawanshi, Shri Dinesh Maurya from BARC

Quasi-non-Destructive Measurement of the Isotopic Ratio of Boron in Irradiated B_4C Pellets from FBTR Control Rods using a Home-built Refelectron Time-of-flight Mass Spectrometer

Dr. M. Joseph, CG, Group Leader

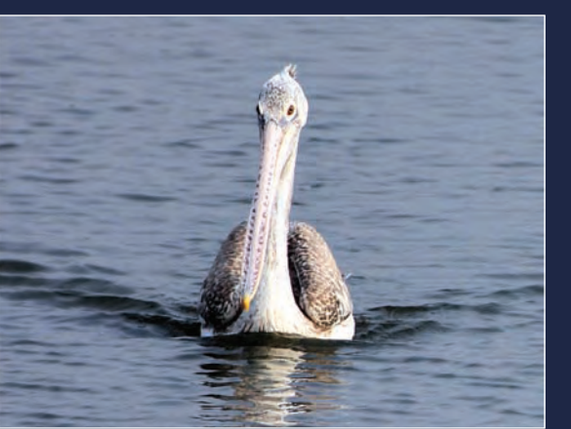
Dr. N. Sivakumar, Dr. P. Manoravi, Shri A. Ananthakumar, Shri M. Saravanan, Shri R. Rajaram, Shri G. Rajendra Prasad and Shri Y. Ravi from CG, Shri V. Anandraj from MMG

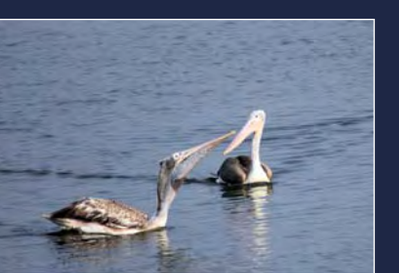
Setting up of an Inert Atmosphere Glove Box Train Facility and Fabrication of Qualified Sodium Bonded Metallic Fuel Pins Containing U-6 Zr, EU-6Zr, U-Pu-Zr Metal Slugs for Test Irradiation in FBTR

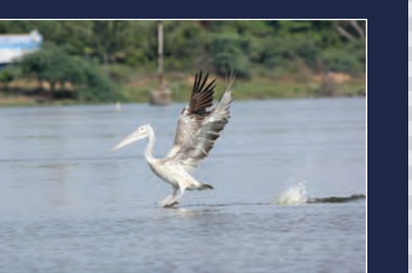
Dr. V. Ganesan, ROMG, Group Leader

Shri G. Ravisankar, Shri A. Ananthakumar, Shri M. Saravanan, Shri G.Rajendra Prasad, Shri Y. Ravi, Shri R.Lavakumar, Shri Abhishek Kumar Yadaw, Shri A. Manivannan, Shri G.Nandha Kumar, Shri M.Masanam, Shri G.Lakshmanan, Shri R.Kumaran, Shri A. V. Vinod, Ms. R. Jayashree, Shri G. Saravanan, Shri A. Senthamilselvan, Shri P. Ravisankar, Shri S. Maharajan, Shri D. Vijayakumar, Shri R. Parthiban, Shri A. Praveen and Shri R. Padmanaban from CG, Shri K. Krishna Chaitanya, Shri P.Narayana Rao, Shri D.Henson Raj, Shri G.Vijayaraghavan, Shri C.Muniyandi from EIRSG, Shri B.S. Ramesh babu, Shri P. Karuppasamy, Shri Mohammed Shijas, Shri M. Praveesh, Shri C. Muthusamy, Shri M. Damodaran and Shri Praveen Kumar from ESG, Shri Hemanth Kumar, Shri M. Arul, Shri G. Srinivasan, Dr. Shaju K. Albert, Dr. Arun Kumar Bhadhuri, Dr. S. Murugan, Shri K.A. Gopal, Shri M. Muthu Ganesh, Shri Rajesh Saxena, Shri R. Ramesh, Shri K. Purushothaman, Shri C.N. Venkiteswaran, Shri A. Vijayaraghavan, Shri Ran Vijay Kumar, Shri V. Anandaraj, Smt. M. Padalakshmi, Shri S. Vinod Kumar and Ms. S. Gomathi from MMG, Shri S. Clement Ravichandar, Shri M. Asokkumar and Shri T Rajkumar from RDG, Shri P. Muralidaran, Shri T.V. Prabhu and Shri M. Santhosh from ROMG

The award is also shared by Shri K K Abdulla, Dr. (Smt.) S.B. Roy, Shri S K Jha, Shri D. Mukherjee, Shri Arbind Kumar, Shri Santanu Das, Shri M T Saify, Shri Raj Kumar, Shri Mukesh Pandit, Shri C K Achankunju, Shri N M Bhoite, Shri Dharmendra Prasad, Shri M.A. Acharekar, Shri Rajendra Prasad, Shri N.D. Sharma, Shri S.K. Sharma and Shri J.R. D'souza from NFG, BARC







Spot Billed Pelican

Dr. M. Sai Baba,
Chairman, Editorial Committee, IGC Newsletter
Editorial Committee Members: Dr. K. Ananthasivan, Shri M.S. Chandrasekar, Dr. N.V. Chandra Shekar, Dr. C. Mallika, Shri K. S. Narayanan, Shri V. Rajendran, Dr. Saroja Saibaba and Dr. Vidya Sundararajan

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